DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT CONCRETE AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOISOTOPES

by

DONALD O. COVAULT

[and others]

Project A-446-7

Engineering Experiment Station
Georgia Institute of Technology
Atlanta, 1959-63

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GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA

December 31, 1959

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Office of Isotopes Development

Subject: Monthly Progress Letter No. 1, Project No. A-446-7
"Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes"
Contract No. AT (38-1)-202
Task No. VII, No Authorization No. Given
Covering the Period from November 23 to December 31, 1959

Gentlemen:

This project is concerned with determining the uniformity of dispersion of portland and asphalt cement throughout a concrete mix for various mixing times. Mixing equipment in the laboratory and at various commercial facilities in the Atlanta area will be utilized in determining the minimum time required to secure a uniform mix. A comparison of mixer efficiencies will be in direct relation to the minimum time obtained.

Dr. Donald O. Covault, Associate Professor of Civil Engineering and a faculty research associate, is director of the project. Dr. Richard C. Palmer, Co-Director of the Radioisotopes Program, is acting as advisor, with no time being charged to the program. Clyde E. Poovey, Jr. is employed as a Graduate Research Assistant.

During the period covered by this report, work has been concentrated on the development of methods to determine the mixing efficiency of portland cement concrete by using radioisotopes. Reference material concerning the use of radioisotopes as tracers, the effect of time of mixing on the strength of concrete and concrete mixer efficiency has been collected and studied. Visits to two portland cement concrete mixing plants were made to determine the feasibility of adding an isotope to the cement.

As an alternate method, an investigation has been made to determine an element inherent in cement that would be practicable for neutron activation studies.

Work scheduled for January 1960 includes investigation and purchase of equipment to meet our particular needs, plotting of a standard count rate graph for known cement-aggregate ratios, and laboratory pilot tests of counting methods and mixing.

Respectfully submitted,

Donald O. Covault
Project Director

Approved:

Earl W. McDaniel
Co-Technical Director

Richard C. Palmer
Co-Technical Director

Wyatt C. Whitley
Co-Technical Director and Chief,
Chemical Sciences Division

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA

January 31, 1960

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Office of Isotopes Development

Subject: Monthly Progress Letter No. 2, Project No. A-446-7
"Determination of the Uniformity of Mixing of Portland Cement, Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes"
Contract No. AT (38-1)-202, Task No. VII
Covering the Period from January 1 to January 31, 1960

Gentlemen:

During the period covered by this report, neutron activation of cast samples of concrete mortar was chosen to determine the uniformity of a dispersion of portland cement throughout a concrete mix. The addition of radioisotopes to the cement has been eliminated because of mixing problems and safety restrictions.

After careful investigation of the different chemical elements inherent in portland cement, calcium has been selected as the most suitable for tracing due to the high energy gamma emissions of calcium-49.

For counting the gamma emissions of activated calcium-49, two 3-inch-diameter by 3-inch-thick scintillation crystals with photo tubes have been purchased from Harshaw Chemical Company, Cleveland, Ohio. Estimated delivery time is March 1, 1960.

Methods of determining mixing efficiency of bituminous concrete have been studied, and neutron activation also appears to be the more practicable solution.

Work scheduled for February includes further investigation of bituminous concrete mixing by visits to plant sites, purchase or fabrication of testing equipment, and the conducting of laboratory tests to determine sampling procedures and techniques for executing experiments.

Respectfully submitted,

Donald O. Covault
Project Director

Approved:

Earl W. McDaniel
Co-Technical Director

Richard C. Palmer
Co-Technical Director

Wyatt C. Whitley
Co-Technical Director and Chief,
Chemical Sciences Division

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA

March 31, 1960

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Office of Isotopes Development

Subject: Monthly Progress Letter No. 3, Project No. A-446-7
"Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes"
Contract No. AT (38-1)-202, Task No. VII
Covering the Period from March 1 to March 31, 1960

Gentlemen:

During the past month, procedures have been developed by which the uniformity of portland cement concrete may be determined. Through the application of statistics, the minimum mixing time necessary to produce concrete of acceptable quality will be found. Furthermore, mixing adequacy of present machinery design can be determined by the manner in which the experiment is designed and the data are evaluated. The experiment has been designed as a factoral experiment. The variables to be evaluated are concerned with the location of the sample in the mixer and the time of mixing.

Techniques in sampling and procedures for processing samples have been developed and tested both in the laboratory and in the field. Sampling devices, sieves for determining gradation uniformity, and molds for casting strength cylinders have been purchased.

Mortar samples of known cement-aggregate content have been cast. These samples will be used to determine standard cement content-count rate graph or chart by neutron activation. This curve will be used to determine the cement content of field samples.

Work scheduled for April concerns the processing of samples taken at a commercial plant for the determination of the uniformity of strength and aggregate dispersion throughout a concrete mix. Mortar samples will also be taken, but testing for cement content by neutron activation will be delayed until a radiation counter is fabricated. Delivery of the two scintillation detectors is scheduled for this month. The two matched preamplifiers and the "adder" have already been received.

Respectfully submitted,

Donald O. Covault
Project Director

Approved:

Earl W. McDaniel
Co-Technical Director

Richard C. Palmer
Co-Technical Director

Wyatt C. Whitley
Co-Technical Director and Chief,
Chemical Sciences Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

April 30, 1960

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Office of Isotopes Development

Subject: Monthly Progress Letter No. 4, Project No. A-446-7
"Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes"
Contract No. AT (38-1)-202, Task No. VII
Covering the Period from April 1 to April 30, 1960

Gentlemen:

Sampling and testing procedures for some of the various concrete batch-plants to be studied have been devised. Two stationary plants are now being investigated. This first plant uses a 2-cubic-yard-capacity mixer of turbine design to produce portland cement concrete. This is a comparatively new mixer design and offers an excellent opportunity for evaluation. The second plant uses a horizontal tilting drum mixer of 3-cubic-yard-capacity to produce portland cement concrete. This is a comparatively old mixer design. Several other mixer designs will be evaluated before this research is completed.

The following tests will be run to determine the uniformity of mixing at the several plants and mixer designs to be studied:

1. Cement content of mortar samples (by neutron activation).

2. Strength of the concrete.

3. Gradation of the aggregate in the concrete.

4. Concrete mixing quality (by visual inspection).

Each variable that is evaluated will be included in a factorial design with two replications. Approximately 90 samples from the turbine mixer and 60 from the horizontal drum mixer will be evaluated for each characteristic of the mix being studied.

The scintillation detectors which were ordered for the detection of gamma radiation from activated calcium-49 have arrived. These detectors are now being checked and a mounting scheme for the crystals and sample is being designed and fabricated.

Work for next month includes the perfection of the counting apparatus for the determination of the cement content of the concrete mortar samples and a continuation of the sampling and testing program.

Respectfully submitted,

Donald O. Covault
Project Director

Approved:

Earl W. McDaniel
Co-Technical Director

Richard C. Palmer
Co-Technical Director

Wyatt C. Whitley
Co-Technical Director and Chief,
Chemical Sciences Division

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA 13, GEORGIA

June 30, 1960

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Office of Isotopes Development

Subject: Monthly Progress Letter No. 5, Project No. A-446-7
"Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes"
Contract No. AT (38-1)-202, Task No. VII
Covering the Period from June 1 to June 30, 1960

Gentlemen:

During the past month, a sampling and testing program to accumulate data by which the mixing uniformity of portland cement concrete may be determined has been in effect. Sixty samples, representing various mixing times from two types of concrete mixes, have been obtained and partially processed. Each sample obtained is evaluated immediately by visual inspection, two mortar samples and a concrete strength cylinder are cast, and the remainder used in a gradation of aggregate test.

The scintillation detectors to be used in determining cement content of cast mortar samples have been permanently mounted and electrically wired, insuring constant geometry during the testing period.

A continuation of the sampling and testing program is scheduled for July including the first analysis of cement content by neutron activation of mortar samples.

Respectfully submitted,

Approved:

Donald O. Covault
Project Director

Fred Sicilio
Co-Technical Director

Richard C. Palmer
Co-Technical Director

Wyatt C. Whitley
Co-Technical Director and Chief,
Chemical Sciences Division

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GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA 13, GEORGIA

July 31, 1960

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Office of Isotopes Development

Subject: Monthly Progress Letter No. 6, Project No. A-446-7
"Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes"
Contract No. AT (38-1)-202, Task No. VII
Covering the Period from July 1 to July 31, 1960

Gentlemen:

During the past month, additional samples of portland cement concrete have been taken and partially tested for uniformity of mixing. A series of laboratory samples were run using a Worthington 6S mixer to give a comparison between rigidly controlled batch measurements and those which exist in the field.

A 1/2-volt sag in the alignment of the Penco 100 channel analyzer used in conjunction with the dual 3-inch scintillation crystals for counting gamma emissions was found and is being corrected. This will necessitate running a new calibration curve to be used in determining cement content of mortar samples.

A continuation of the sampling and testing program is scheduled for August. Emphasis will be placed on the determination of cement content by neutron activation.

Approved: Respectfully submitted,

Fred Sicilio
Co-Technical Director

Donald O. Covault
Project Director

Richard C. Palmer
Co-Technical Director

Wyatt C. Whitley
Co-Technical Director and Chief,
Chemical Sciences Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

September 30, 1960

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Office of Isotopes Development

Subject: Monthly Progress Letter No. 7, Project No. A-446-7
"Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes"
Contract No. AT (38-1)-202, Task No. VII
Covering the Period from September 1 to September 30, 1960

Gentlemen:

A short neutron target tube attachment to the Van De Graaff for activation of concrete mortar samples with neutrons has been purchased from High Voltage Engineering Co. with Georgia Tech overhead funds. Associated equipment, such as a neutron moderator (paraffin) and a sample holder, has been fabricated. After this equipment is installed and checked, activation analysis can begin. Nearly 300 samples of concrete mortar are ready for activation and counting.

The concrete sampling program has been continued and will include two additional concrete ready-mix plants in the Atlanta area. Both of these plants have 3-cubic-yard horizontal drum mixers.

Plans for next month include activation analysis of the concrete mortar specimens already collected and continued sampling of the two additional concrete ready-mix plants.

Approved:

Sincerely yours,

Fred Sicilio
Co-Technical Director

Donald O. Covault
Project Director

Richard C. Palmer
Co-Technical Director

Wyatt C. Whitley
Co-Technical Director and Chief,
Chemical Sciences Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

October 31, 1960

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Office of Isotopes Development

Subject: Monthly Progress Letter No. 8, Project No. A-446-7
"Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes"
Contract No. AT (38-1)-202, Task No. VII
Covering the Period from October 1 to October 31, 1960

Gentlemen:

Efforts during the last month have been concentrated on the development and refinement of a procedure for the determination of the cement content of mortar samples by neutron activation. Samples of cement mortar of known cement content were activated in the Van De Graaff and the calcium-49 produced was counted in the Penco 100 channel analyser. Count rates with energies above 2.0 Mev were determined for each known cement content. A calibration curve of cement content versus count rate was then plotted with this information.

The same series of mortar samples was activated by the Van De Graaff several times after the activity had completely decayed for each run and several calibration curves were determined. These curves did not reproduce each other and evidence indicates some variation in the operation of the Van De Graaff is causing this difference.

Plans for next month will be concerned with finding the cause for this difference in calibration curves and the completion of the sampling of the final stationary concrete mixer to be considered in this project.

Approved:

Respectfully submitted,

Fred Sicilio
Co-Technical Director

Donald O. Covault
Project Director

Richard C. Palmer
Co-Technical Director

Wyatt C. Whitley, Chief
Chemical Sciences Division
Co-Technical Director

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA 13, GEORGIA

December 31, 1960

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Office of Isotopes Development

Subject: Monthly Progress Letter No. ~~10~~ 9, Project No. A-446-7
"Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes"
Contract AT (38-1)-202, Task No. VII
Covering the Period from December 1 to December 31, 1960

Gentlemen:

The testing program for this phase of the project was completed this month, and data for the final report are now being analyzed. A rough draft of the final report will be completed by the end of January and the completed report will be ready for submission in February.

A proposal for the extension of this project is now being drafted and will be submitted within a few weeks. The proposal extension will be concerned with the mixing problems associated with bituminous cement concrete.

Respectfully submitted,

Donald O. Covault
Project Director

Approved:

Fred Sicilio
Co-Technical Director

Richard C. Palmer
Co-Technical Director

Wyatt C. Whitley
Co-Technical Director and Chief,
Chemical Sciences Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA
January 31, 1961

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Office of Isotopes Development

Subject: Monthly Progress Letter No. 10, Project No. A-446-7
"Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes"
Contract No. AT (38-1)-202, Task No. VII
Covering the Period from January 1 to January 31, 1961

Gentlemen:

The rough draft of the final report is being prepared. This draft will be completed during February or early in March. A proposal for the extension of this report has been drafted. This proposal will be concerned with the mixing problems of bituminous cement concrete.

Respectfully submitted,

Donald O. Covault
Project Director

Approved:

Fred Sicilio
Co-Technical Director

Richard C. Palmer
Co-Technical Director

Wyatt C. Whitley
Co-Technical Director and Chief,
Chemical Sciences Division

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA 13, GEORGIA

April 30, 1961

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Office of Isotopes Development

Subject: Monthly Progress Letter No. 12, Project No. A-446-7
"Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes"
Contract No. AT (38-1)-202, Task No. VII
Covering the Period from April 1 to April 30, 1961

Gentlemen:

Final details associated with the publication of the final report covering the portland cement concrete phase of this project has been completed. The report is being reproduced and should be submitted shortly for review.

Respectfully submitted,

Donald O. Covault
Project Director

Approved:

Fred Sicilio
Co-Technical Director

Richard C. Palmer
Co-Technical Director

Wyatt C. Whitley
Co-Technical Director and Chief
Chemical Sciences Division

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA 13, GEORGIA

May 31, 1961

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Office of Isotopes Development

Subject: Monthly Progress Letter No. 12, Project No. A-446-7
"Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes"
Contract No. AT (38-1)-202, Task VII
Covering the Period from May 1 to May 31, 1961

Gentlemen:

Investigation has been initiated for the second phase of this project dealing with the mixing uniformity of bituminous concrete. Various methods and equipment for the measurement of neutron back scatter are now being studied. Equipment for the measurement of moisture content in soil that has been developed by the Nuclear Chicago Company and other manufacturers is being investigated to ascertain if this equipment can be used to measure asphaltic content in a bituminous mixture.

An investigation is also being initiated to determine the most feasible manner in which to measure the aggregate portions of the bituminous concrete mixture by neutron activation.

Approved: Respectfully submitted,

Fred Sicilio
~~Co~~-Technical Director

Donald O. Covault
Project Director

Richard C. Palmer
Co-Technical Director

Wyatt C. Whitley
Co-Technical Director and Chief,
Chemical Sciences Division

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GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA 13, GEORGIA

July 31, 1961

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Office of Isotopes Development

Subject: Monthly Progress Letter No. 13, Project No. A-446-7, "Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes"
Contract No. AT (38-1)-202, Task No. VII
Covering the Period from July 1 to July 31, 1961

Gentlemen:

Revision of the recently submitted annual report dealing with an investigation of the mixing problems of portland cement concrete is now being completed. This revision is being done in conformance with suggestions and comments made by Mr. George Magin and a group of consultants who reviewed the report.

Investigation of gauges required to measure neutron backscatter is also being continued in conjunction with source material and source strength required to measure asphaltic content of bituminous mixes. Present investigation indicates that a plutonium-beryllium or actinium-beryllium source can be purchased with adequate activity levels to measure asphaltic content.

A tritium target for the Van de Graaff accelerator has been ordered. This target will produce higher neutron fluxes for activation analysis than can be produced by the beryllium target used presently in the Van de Graaff. The higher flux requires a revision of the shielding of the Van de Graaff. This shielding is now being designed and will be constructed in the near future.

Plans for next month will be concerned with the completion of the revision of the annual report and with work on the shielding of the Van de Graaff.

Approved:

Fred Sicilio
Co-Technical Director

Richard C. Palmer
Co-Technical Director

Wyatt C. Whitley
Co-Technical Director and Chief,
Chemical Sciences Division

Respectfully submitted,

Donald O. Covault
Project Director

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA 13, GEORGIA

August 31, 1961

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Office of Isotopes Development

Subject: Monthly Progress Letter No. 14, Project No. A-446-7 "Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes" Contract No. AT (38-1)-202, Task No. VII
Covering the Period from August 1 to August 31, 1961

Gentlemen:

Revision of the recently submitted annual report is now complete and it has been submitted for printing. The completed reports will be distributed during September.

The shielding required for the Van de Graaff has been designed and the design checked by Dr. David W. Martin of the Radioisotopes Laboratory. The Nuclear Chicago d/M gauge is being studied for its capabilities for measurement of asphaltic content with an actinium-beryllium or plutonium-beryllium source. The shielding will be constructed and the neutron back scatter gauge with the appropriate source will be ordered as soon as permission for funding the cost of this additional work is received. A letter was recently submitted to Mr. Palmer at the Operations Office at Savannah River describing in detail the work to be done for the requested additional $2800.00.

Respectfully submitted,

Donald O. Covault
Project Director

Approved:

Richard C. Palmer
Co-Technical Director

Wyatt C. Whitley
Co-Technical Director and Chief,
Chemical Sciences Division

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GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA 13, GEORGIA

October 31, 1961

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Division of Isotopes Development

Subject: Monthly Progress Letter No. 15, Project No. A-446-7
"Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes"
Contract No. AT (38-1)-202, Task No. VII
Covering the Period from October 1 to October 31, 1961

Gentlemen:

Samples to determine the dimensions required for infinite size for the determination of asphaltic content of bituminous concrete are now being made and tested using the d-M gauge developed by Nuclear Chicago Corporation. Tests to this date indicate that the sample size must be approximately 24 inches square and six inches deep. Tests are being made using different types of backing material under the asphaltic mixture. Backing materials such as wood and concrete, which contain a large quantity of hydrogen, show substantial influence on the readings recorded using the surface moisture probe of the d-M gauge when the samples are less than six inches in depth.

The tritium target and associated apparatus for the Van de Graaf have arrived and will be installed during the month of November. The water shielding for the Van de Graaf is about 50 per cent complete.

Respectfully submitted,

Donald O. Covault
Project Director

Approved:

R. C. Palmer
Co-Technical Director

Wyatt C. Whitley
Co-Technical Director and Chief,
Chemical Sciences Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

November 30, 1961

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Division of Isotopes Development

Subject: Monthly Progress Letter No. 16, Project No. A-446-7
"Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes"
Contract No. AT (38-1)-202, Task No. VII
Covering the Period from November 1 to November 30, 1961

Gentlemen:

Sample size dimensions required for infinite size for the determination of asphaltic content of bituminous concrete mixture using neutron backscatter is still under study. A series of samples of the similar asphaltic content and gradation were tested during this past month. These samples were 24 inches wide, 24 inches long, and varied in depth from 1 to 11 inches. The infinite thickness was determined to be approximately 10 inches. A curve showing the results obtained for the Model P-21 moisture probe developed by the Nuclear Chicago Corporation is shown in Figure 1.

Minimum dimensions in length and width of specimen are now being studied. Preliminary results indicate that the length and width of the sample can be much less than 24 inches and not influence neutron backscatter measurements. The infinite thickness curve shown in Figure 1 is for an asphaltic content of 6.25 per cent by weight. The influence of other asphaltic contents will also be investigated.

Respectfully submitted,

Approved:

Donald O. Covault
Project Director

Richard C. Palmer
Co-Technical Director

Wyatt C. Whitley
Co-Technical Director and Chief
Chemical Sciences Division

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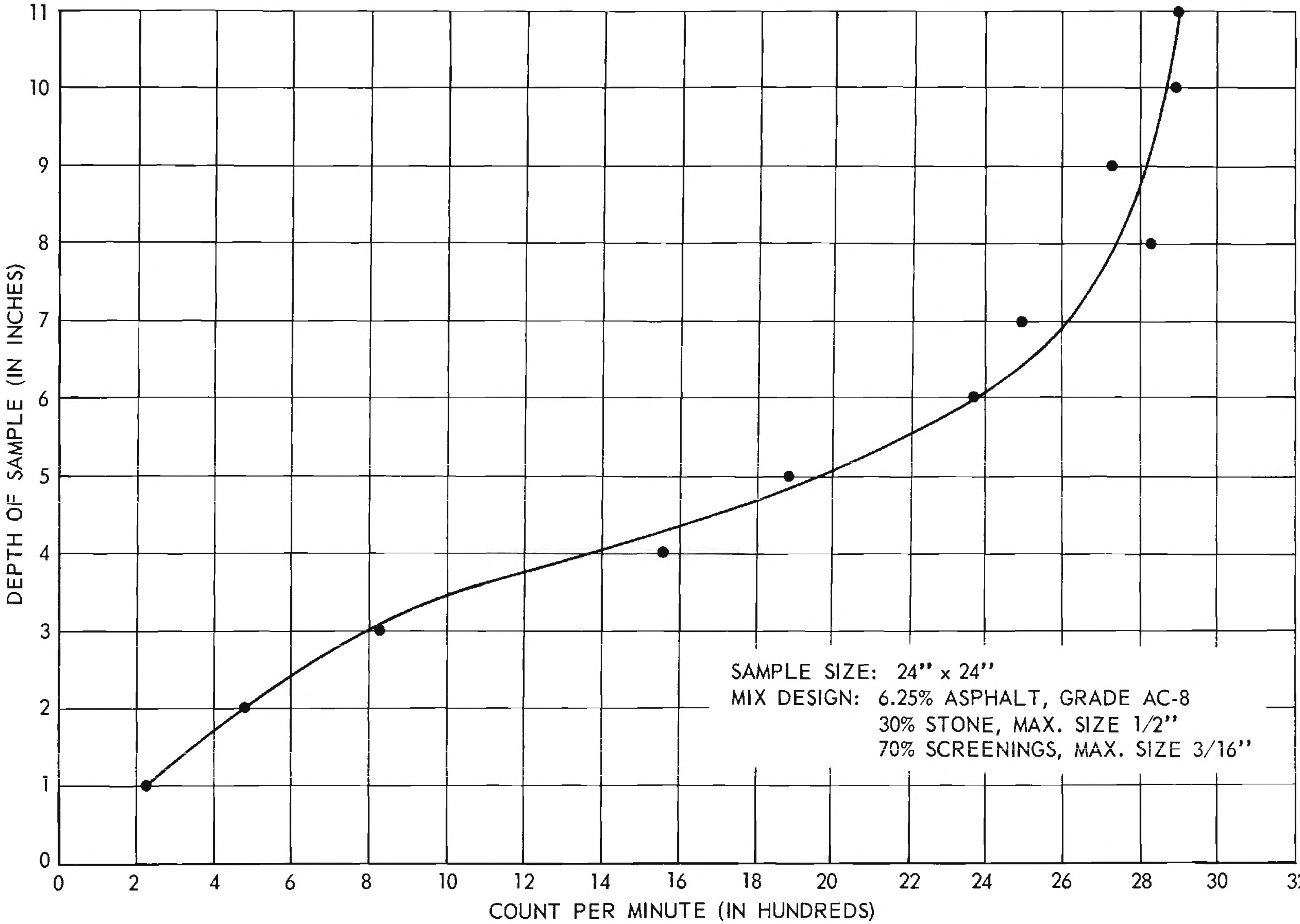

DETERMINATION OF INFINITE SAMPLE THICKNESS USING
MODEL P-21 MOISTURE PROBE BY
NUCLEAR – CHICAGO

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

January 31, 1962

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Division of Isotopes Development

Subject: Monthly Progress Letter No. 17, Project No. A-446-7
"Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes"
Contract No. AT (38-1)-202, Task No. VII
Covering the Period from January 1 to January 31, 1962

Gentlemen:

A paper entitled, "Use of Neutron Activation Analysis to Determine Content of Portland Cement Concrete" was presented to the annual meeting of the Highway Research Board on January 9, 1962. This paper covered the major findings on this project dealing with portland cement concrete.

While in Washington, D. C., attending the Highway Research Board meetings, I held meetings with Mr. George Magin and Mr. Jack Dempsy (Atomic Energy Commission), and Mr. Norman Cohen and Mr. Blackwell (Bureau of Public Roads) and discussed problems associated with the present phase of the work dealing with bituminous concrete. I also discussed some of these problems with individuals at the Highway Research Board who are concerned with the use of radioisotopes in civil engineering.

I concluded from these discussions and supplemental reading that the determination of asphaltic content of bituminous mixture by neutron backscatter was not possible if the bituminous mixture has been placed in layers from 1 to 3 inches in thickness. A literature study indicates that determination of asphaltic content using direct attenuation methods is possible, however.

Work during the month of January was concerned with investigation of the feasibility of using neutron backscatter techniques for measurement of asphaltic content of bituminous mixtures. Work was also continued on the preparation of the Van de Graaff for neutron activation analysis. Neutron activation analysis will be used to determine the dispersion of mineral filler in a bituminous mixture.

Consideration and choice of the type of bituminous concrete mixing equipment to be sampled in the research was also made during this month. Several highway paving projects in the vicinity of Atlanta are being used.

Respectfully submitted

Donald O. Covault
Project Director

Approved:

Wyatt C. Whitley
Co-Technical Director and Chief,
Chemical Sciences Division

GEORGIA INSTITUTE OF TECHNOLOGY

ENGINEERING EXPERIMENT STATION

ATLANTA 13, GEORGIA

February 28, 1962

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Division of Isotopes Development

Subject: Monthly Progress Letter No. 18, Project No. A-446-7
"Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes"
Contract No. AT (38-1)-202, Task No. VII
Covering the Period from February 1 to February 28, 1962.

Gentlemen:

Construction of the water shield for the Van de Graff has been completed, and it is now being installed. The activation equipment for the shield has been purchased and the shield is ready for installation.

Dimensions of the bituminous concrete for the evaluation of mineral filler content samples to be irradiated with neutrons have been determined to be 0.75 inch in diameter by 0.75 inch high. This determination was based on the amount of calcium-49 necessary to produce a statistically reliable count.

Samples of the mineral filler and aggregate portions of several proposed bituminous concrete mixes have been obtained and are at present undergoing chemical analysis.

Test procedures and sampling techniques are under investigation prerequisite to preparation of standard samples.

Respectfully submitted,

Donald O. Covault
Project Director

Approved:

Wyatt C. Whitley, Chief
Chemical Sciences Division

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GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

May 1, 1962

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Division of Isotopes Development

Subject: Monthly Progress Letter No. 19, Project No. A-446-7
"Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes"
Contract No. AT (38-1)-202, Task No. VII
Covering the Period from April 1 to April 30, 1962

Gentlemen:

Preparation of standard samples containing known amounts of mineral filler has been completed. The range of mineral filler in the standard samples compares to the range of mineral filler normally found in bituminous concretes, i.e., from 2 to 6 per cent by total weight of mix. A sample holder has been modified so that the standard samples can be properly positioned for neutron activation under the tritium target.

Sampling of the Georgia Tech Hobart Model C-100 laboratory mixer has been completed. Samples were taken for mineral filler cement determination by neutron activation, gradation determination, and the determination of strength characteristics for five different mixing times for two replications.

Field sampling dates have been set for three State Highway projects in the Atlanta area. These dates are in May, June, and July. Preparation for the May sampling is complete.

An annual report for this project is due on May 30, 1962. It is felt that progress to date has not produced sufficient data to warrant the time and money expenditure required to write and reproduce this annual report. As the project program now stands, collection and analysis of data will be complete in October with a final report forthcoming by the end of the year.

Respectfully submitted,

Donald O. Covault
Project Director

Approved:

Wyatt C. Whitley, Chief
Chemical Sciences Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

June 1, 1960

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Division of Isotopes Development

Subject: Monthly Progress Letter No. 20, Project No. A-446-7
"Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes"
Contract No. AT (38-1)-202, Task No. VII
Covering the Period from May 1 to May 31, 1962

Gentlemen:

Sampling of the Cedar Rapids G-40 Asphalt Hot Mix Plant owned by McIntosh Paving Company at Tyrone, Georgia, has been completed. The sampled mix design required 6.5% AC-6 asphalt content by weight, local granititic aggregates, and 2.74% mineral filler content by weight.

The mix was sampled at five mixing times which ranged from 30 seconds to 180 seconds for two replications. Both mixing times and replications were randomized. Three samples were taken from each timed batch at points representative of three different points within the mixing equipment.

Preparations for the June field sampling have been completed. The tentative date set for this sampling is June 11, 1962.

Guide tracks for the water shield door for the Van de Graff are being installed. Installation of the shield should be complete in June.

Respectfully submitted,

Donald O. Covault
Project Director

Approved:

Frederick Bellinger, Chief
Chemical and Material Science Divisions

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

July 2, 1962

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Division of Isotopes Development

Subject: Monthly Progress Letter No. 21, Project No. A-446-7
"Determination of Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by Use of Radioisotopes"
Contract No. AT (38-1)-202, Task No. VII
Covering the Period from June 1 to June 30, 1962

Gentlemen:

Fabrication of specimens of asphaltic concrete for Marshall stability and neutron activation was started in June using material collected in sampling the Georgia Tech Laboratory mixer and a hot mix plant owned by McIntosh Paving Company in Tyrone, Georgia.

On June 8, 1962, I attended a meeting held in the Atomic Building in Washington with members of the Atomic Energy Commission and the Bureau of Public Roads. The subject of discussion was this project. The consensus of the meeting was that present work be concluded as soon as possible and that work be started to develop a gage to measure asphaltic content of bituminous mixtures. Toward this objective, field sampling dates in June and July were canceled.

Before the conclusion of the present work on the project, a new proposal to develop a gage to measure asphaltic content of bituminous mixtures will be submitted. Work under the new proposal tentatively will be financed jointly by Atomic Energy Commission funds, the Georgia State Highway Department and the Bureau of Public Roads. Needed investigation and literature search necessary for the preparation of this new proposal is now in progress.

Respectfully submitted,

Donald O. Covault
Project Director

Approved:

Frederick Bellinger, Chief
Chemical and Material Science Divisions

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

September 3, 1962

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Division of Isotopes Development

Subject: Monthly Progress Letter No. 22, Project No. A-446-7
"Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes"
Contract No. AT (38-1)-202, Task No. VII
Covering the Period from August 1 to August 31, 1962

Gentlemen:

With the goal of relating strength, gradation, and mineral filler content, bituminous concrete samples were collected and made into test specimens. Testing of specimens for Hveem stability is complete. Gradation analysis is now underway on the samples collected for this purpose.

Data collected to date has been reduced in preparation for the statistical analysis. Activation analysis was started and the results indicate a linear relationship between count rate and mineral filler content. Activation analysis was temporarily suspended due to progressive failure of the ion source on the Van de Graaff.

During the next month the activation analysis will be completed and analysis of data will begin.

Respectfully submitted,

Donald O. Covault
Project Director

Approved:

Frederick Bellinger, Chief
Chemical Sciences & Materials Division

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GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

November 12, 1962

U. S. Atomic Energy Commission
1717 H. Street, N.W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Division of Isotopes Development

Subject: Monthly Progress Letter No. 23, Project No. A-446-7
"Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes"
Contract No. AT (38-1)-202, Task No. VII
Covering the Period from October 1 to October 31, 1962

Gentlemen:

Regression analysis to determine the relationship between count rate and mineral filler is complete. A linear relationship was found to exist, however, credence cannot be given to the results because of a low sample correlation coefficient. The low correlation might be attributed to any one or a combination of several things. First, the percentage of mineral filler used in bituminous concrete is small and leads to poor counting statistics for the calcium count rate. Second, the increase in size of the counted sample in comparison to the size required for Portland cement testing introduced possibilities of self-shielding. And third, in order to produce sufficient neutron flux, the Van de Graaff was operated at its marginally stable maximum potential and current.

Rich Electronic Computer Center has completed the basic calculations necessary for the analysis of variance. This analysis is at present very near completion.

Preparation of the final project report has started and will continue throughout November.

Respectfully submitted,

Donald O. Covault
Project Director

Approved:

Frederick Bellinger, Chief
Chemical Sciences & Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

December 11, 1962

U. S. Atomic Energy Commission
1717 H. Street, N. W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Division of Isotopes Development

Subject: Monthly Progress Letter No. 24, Project No. A-446-7
"Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes."
Contract No. AT (38-1)-202, Task No. VII
Covering the Period from November 1 to November 30, 1962.

Gentlemen:

Preparation of the final project report is underway and should be completed by the end of the year.

A presentation of the project work is being prepared and will be given at the Annual Contractors Conference in Oak Ridge, Tennessee, on December 3, 1962.

Respectfully submitted,

Donald O. Covault
Project Director

Approved:

Frederick Bellinger, Chief
Chemical Sciences & Materials Division

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QUARTERLY TECHNICAL STATUS REPORT NO. 1

PROJECT NO. A-446-7

DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT CONCRETE AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOISOTOPES

By

DONALD O. COVAULT

COVERING THE PERIOD
23 NOVEMBER 1959 to 29 FEBRUARY 1960
Printed 9 March 1960

CONTRACT NO. AT (38-1)-202, TASK NO. VII
Placed By
UNITED STATES ATOMIC ENERGY COMMISSION
SAVANNAH RIVER OPERATIONS OFFICE
AIKEN, SOUTH CAROLINA

Performed for
UNITED STATES ATOMIC ENERGY COMMISSION
OFFICE OF ISOTOPES DEVELOPMENT
GERMANTOWN, MARYLAND

Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia

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ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY TECHNICAL STATUS REPORT NO. 1

PROJECT NO. A-446-7

DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT CONCRETE AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOISOTOPES

By

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COVERING THE PERIOD
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CONTRACT NO. AT (38-1)-202, TASK NO. VII
Placed By
UNITED STATES ATOMIC ENERGY COMMISSION
SAVANNAH RIVER OPERATIONS OFFICE
AIKEN, SOUTH CAROLINA

Performed for
UNITED STATES ATOMIC ENERGY COMMISSION
OFFICE OF ISOTOPES DEVELOPMENT
GERMANTOWN, MARYLAND

ABSTRACT

Reference material concerning the use of radioisotopes as tracers, and the effect of time of mixing on the strength of concrete, and mixer efficiency has been collected and studied.

After an examination of plant facilities and investigation of the different possibilities of executing the experiment, neutron activation of cast cement mortar samples was selected as the most promising method for determining the mixing efficiency of concrete.

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This report contains 7 pages.

I. INTRODUCTION

This report summarizes the work performed from November 23, 1959, to February 29, 1960. The purpose of work under this contract is to determine the uniformity of mixing of portland cement concrete and bituminous concrete for various mixing times by the use of radioisotopes.

During the past quarter, emphasis was placed on the development of methods to determine the mixing efficiency of portland cement concrete.

II. DISCUSSION

A. Personnel

Dr. Donald O. Covault, Associate Professor of Civil Engineering and a faculty research associate, is Director of the project. Dr. Richard C. Palmer, Co-Director of the Radioisotopes Program, is acting as advisor. Clyde E. Poovey, Jr. is employed as a graduate research assistant.

B. Reference Material

Approximately one-half of this first quarter has been devoted to collecting and studying information about the use of radioisotopes as tracers in mixing operations, the efficiency of concrete mixers, and the effect of mixing time on the strength of concrete.

C. Experiment Design

The remaining time of the past quarter has been used primarily in developing methods of determining the uniformity of dispersion of portland cement throughout a concrete mix.

The addition of radioisotopes to the portland cement was initially considered as a tracer of portland cement. After visiting several commercial facilities in the Atlanta area, the investigators concluded that it was impossible to mix uniformly an isotope with the cement. Also, as the cement is discharged from the storage hopper, radioactive dust might contaminate the immediate area.

Neutron activation of cast concrete samples was investigated and determined practicable. The cement content of these samples would be based on the amount of calcium found present in the portland cement. Portland cement contains approximately 65 per cent calcium oxide. The coarse aggregate used at local plants cooperating with Georgia Tech in this project is a biotite granite gneiss containing only a trace of calcium and the fine aggregate contains no calcium. Typical chemical constituents of portland cement, coarse aggregate, and fine aggregate used in this study are shown in Table I.

TABLE I

CHEMICAL CONSTITUENTS OF PORTLAND CEMENT AND FINE AND COARSE AGGREGATE

Chemical Compound	Per Cent By Weight
Portland Cement	
CaO	65.66
SiO_2	22.24
Al_2O_3	5.96
Fe_2O_3	2.16
SO_3	1.88
MgO	.93
Ins. Res.	.4
Na_2O	.03
K_2O	.15
Fine Aggregate	
SiO_2	98.0
Al_2O_3	1.2
Fe_2O_3	.06
H_2O	.56
Org. Matter	.18
Coarse Aggregate	
SiO_2	74.70
Al_2O_3	13.92
Fe_2O_3	3.84
CaO_3	3.76
MgO	0.20
Na_2O	2.80
K_2O	0.76

Activated calcium-49 with its high energy gamma emissions was selected as the isotope to trace. By activating samples and counting calcium-49, a determination of the cement content can be made by comparison of the count to a known cement-count rate chart.

Samples are being made under laboratory control of known cement-aggregate content. These samples will be activated and counted and will provide a standard cement content-count rate chart or graph. Figure 1 is a photograph of cement mortar samples which are being activated to determine the cement content-count rate curve. The samples are approximately 3/4 of an inch in diameter and 1/4 of an inch in thickness.

Field samples of mortar taken at various mixing times throughout a given mix may then be checked for variation of cement content by neutron activation. The minimum time required to obtain a uniform mix may be determined for various types of mixer designs.

Two 3-inch-diameter by 3-inch-length scintillation crystals with photo tubes to be used in counting the gamma emissions of calcium-49 have been ordered from the Harshaw Chemical Company, Cleveland, Ohio. Delivery is scheduled for April.

III. FUTURE PROGRAM

The immediate program will be concerned with making the known cement-aggregate content samples. Activation of these samples and plotting of a standard cement content count-rate graph will follow. After receipt of the scintillation crystals, determination of the minimum time required to secure a uniform mix in a laboratory mixer and techniques to be used in sampling will be included in the coming quarter.

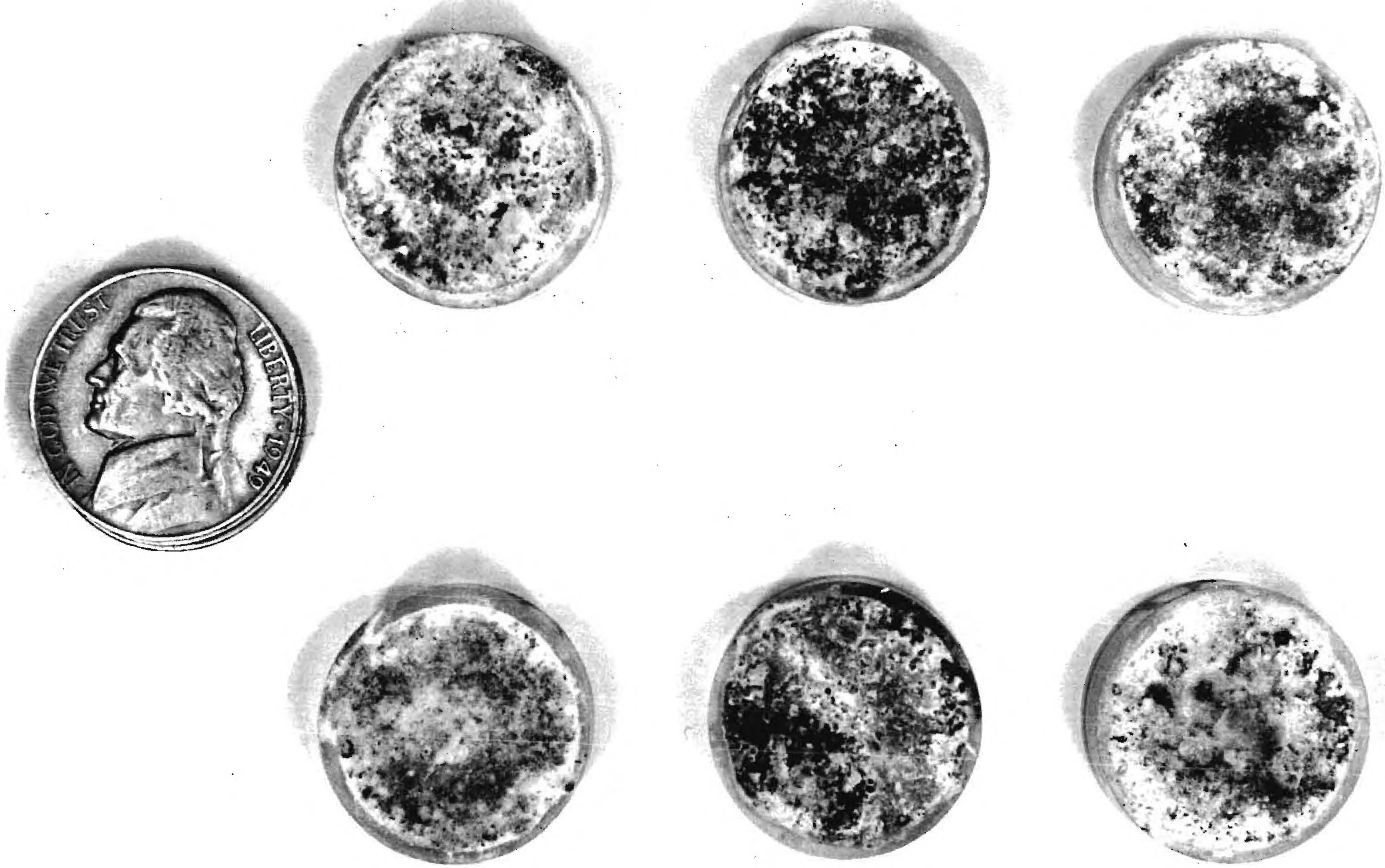

Figure 1. Photograph of Cement Mortor Samples Used for Neutron Activation (Note comparative size with nickel)

A method for determining the uniformity of bituminous concrete mixes will be resolved.

Respectfully submitted:

Donald O. Covault
Project Director

Approved:

Earl W. McDaniel
Co-Technical Director

Richard C. Palmer
Co-Technical Director

Wyatt C. Whitley
Co-Technical Director and Chief,
Chemical Sciences Division

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QUARTERLY TECHNICAL STATUS REPORT NO. 2

PROJECT NO. A-446-7

DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT CONCRETE AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOISOTOPES

By

DONALD O. COVAULT

COVERING THE PERIOD
1 MARCH 1960 to 31 MAY 1960
PRINTED 10 JUNE 1960

CONTRACT NO. AT (38-1)-202
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Performed for
UNITED STATES ATOMIC ENERGY COMMISSION
OFFICE OF ISOTOPES DEVELOPMENT
GERMANTOWN, MARYLAND

Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY TECHNICAL STATUS REPORT NO. 2

PROJECT NO. A-446-7

DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT CONCRETE AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOISOTOPES

By

DONALD O. COVAULT

COVERING THE PERIOD
1 MARCH 1960 to 31 MAY 1960
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UNITED STATES ATOMIC ENERGY COMMISSION
SAVANNAH RIVER OPERATIONS OFFICE
AIKEN, SOUTH CAROLINA

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OFFICE OF ISOTOPES DEVELOPMENT
GERMANTOWN, MARYLAND

ABSTRACT

All equipment has been obtained and all procedures developed for collecting, testing, and analyzing samples. Three types of concrete mixers will be evaluated for mixing efficiency at different time lengths for mixing. These mixers are the turbine type, horizontal drum, and the dual drum designs. Preliminary investigation of the determination of cement content of cement mortar samples by neutron activation has indicated that this procedure is feasible.

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B. Sampling Plan. 1

C. Evaluation of Mixer Design 2

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III. FUTURE WORK. 7

This report contains 7 pages.

Quarterly Technical Status Report No. 2, Project No. A-446-7

I. INTRODUCTION

The report summarizes the work performed on this project from March 1, 1960, to May 31, 1960. During the quarter, emphasis was placed on the continued development of methods to determine the mixing efficiency of portland cement concrete and on the evaluation of the methods by which this could be done.

II. DISCUSSION

A. Experimental Design

All sampling and testing will be done in such a manner that the several variables which influence mixing efficiency -- such as mixer design, time of mixing, dispersion of cement in a concrete mix, gradation of aggregate, compressive strength of concrete, and visual determination of mixing efficiency -- can be evaluated. In order to make this evaluation rationally and with a minimum of effort, all experiments will be evaluated statistically in a factorial design experiment devised with the help of Professor Joseph Moder of the Department of Industrial Engineering of Georgia Tech.

B. Sampling Plan

Several types of portland cement concrete mixer designs will be evaluated in this research. Also, mixing efficiency for a specified mixer will be evaluated for various mixer times. The times to be considered are as follows:

30 seconds
45 seconds
60 seconds
120 seconds
180 seconds

Samples will be taken at each one of these times so that the several variables mentioned previously can be evaluated. The experiment has been devised as a completely randomized design so that bias involved in drawing samples and testing can be reduced. Approximately 240 samples shall be drawn for each mixer design to indicate how cement content, concrete strength, aggregate and gradation of the aggregate vary and how characteristics of mixer design and time of mixing influence mixing efficiency.

C. Evaluation of Mixer Designs

Three portland cement concrete mixer designs will be evaluated. These designs are as follows:

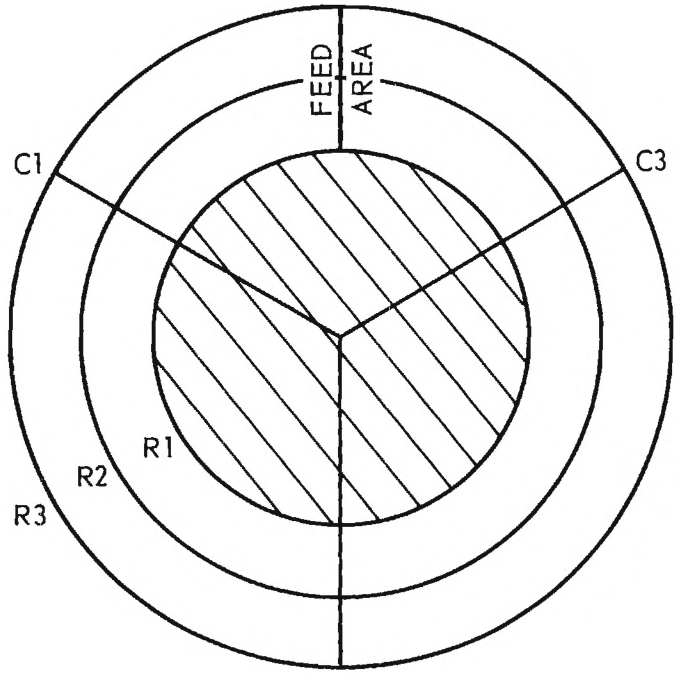
1. Turbine Mixer (3-cubic-yard-capacity)
2. Horizontal Drum Mixer (3-cubic-yard-capacity)
3. Dual Drum Mixer (1.26-cubic-yard-capacity)

The turbine type mixer is used by a commercial producer of ready-mix concrete in the Atlanta area. This mixer is a comparatively recent design and is not used extensively for concrete production. A data sheet that will be used for recording sample information for this mixer design is shown in Figure 1.

The horizontal drum mixer is a comparatively old mixer design. This type of mixer has been used for many years to produce concrete for large dams, highways, and other large reinforced concrete structures.

The dual drum concrete mixer has also been used for a number of years to produce concrete. This type of mixer has not been used to a great extent to produce concrete at a stationary plant location. The dual drum paver has been used primarily for the production of concrete for highway pavements at

Uniformity of Concrete Mix
Project A446-7
Date: ____________



Type Mixer: Turbine
Site: MacDougald-Warren Plant, Northside Drive

Concrete Specifications ____________
Volume Mixed ____________ yds.
Mixing Time ____________ secs.
Sample Drawn ____________

VISUAL INSPECTION OF MIXING UNIFORMITY

Poor ______ Average ______ Good ______

COMPRESSIVE STRENGTH TEST

Cylinder Number ____________ Testing Date ____________
28 Day Failure Load ____________ lbs. Compressive Strength ____________ lbs/sq. inch

CEMENT CONTENT BY NEUTRON ACTIVATION

Weight Mortar Sample ____________ grams Sample Number ____________
Count: ____________ Cement Content ____________ grams Cement-Mortar Ratio ______ gm/gm

SIEVE ANALYSIS

Total Weight Sample ____________ Weight Sample at Split ____________

Sieve Size	Weight Retained	Cumulative Weight Retained	Cumulative Percent Retained
No. 1-1/2	______	______	______
3/4	______	______	______
3/8	______	______	______
	______	______	______
	______	______	______
	______	______	______
	______	______	______
50	______	______	______
100	______	______	______
200	______	______	______
	______	______	______

Fineness Modulus ____________

1	______
1/2	______

Figure 1. Data Sheet for Turbine Mixer.

the job site because of its mobility. The dual drum mixer which will be sampled is being used on a large highway pavement project near Atlanta.

D. Determination of Cement Content

Cement content of the concrete mortar will be determined by neutron activation of samples of the cement mortar. A complete description of this procedure was outlined in Quarterly Report No. 1 for this project. Determination of cement content is made by counting the level of activity of calcium-49 in the cement mortar. Small disks of mortar of known cement content will be activated in a Van de Graaff, and a curve will be drawn of count rate versus cement content. Unknown cement contents can be determined by activating a sample of the mortar and counting the level of radioactivity, and by comparing the count rate to the curve of count rate versus cement content. Because calcium-49 has high energy gamma emissions (above 2 mev), the amount of calcium in the cement contained in mortar can be determined by counting the activities at these energy levels. A sample of pure calcium and cement mortar were activated in the Van de Graaff located in the Radioisotopes and Bioengineering Laboratory at Georgia Tech. The radioactivity of these samples was determined in a Penco 100 channel analyser. Delivery of two scintillation detectors, matched preamplifiers, and adder was made a few weeks ago and this equipment was also used in the counting of activity level. The two scintillation detectors are arranged in such a manner that 4π geometry is very nearly obtained.

Figure 2 shows the results obtained when a pure calcium sample and a cement mortar sample were activated. Peaks and corresponding energy levels can be noted in curves for the various channels.

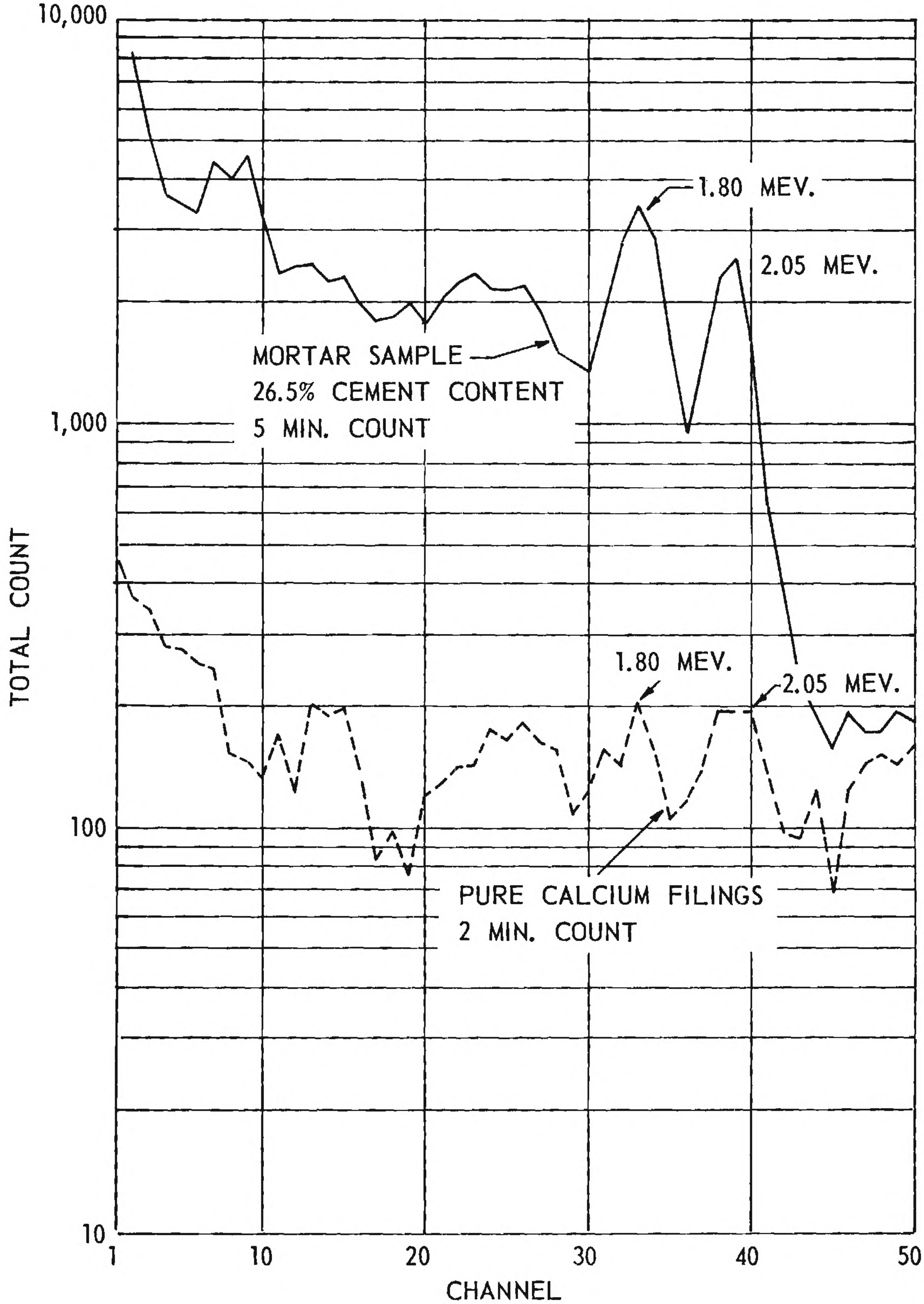


Figure 2. Count Rate Versus Channel Number Obtained by Penco 100 Channel Analyzer.

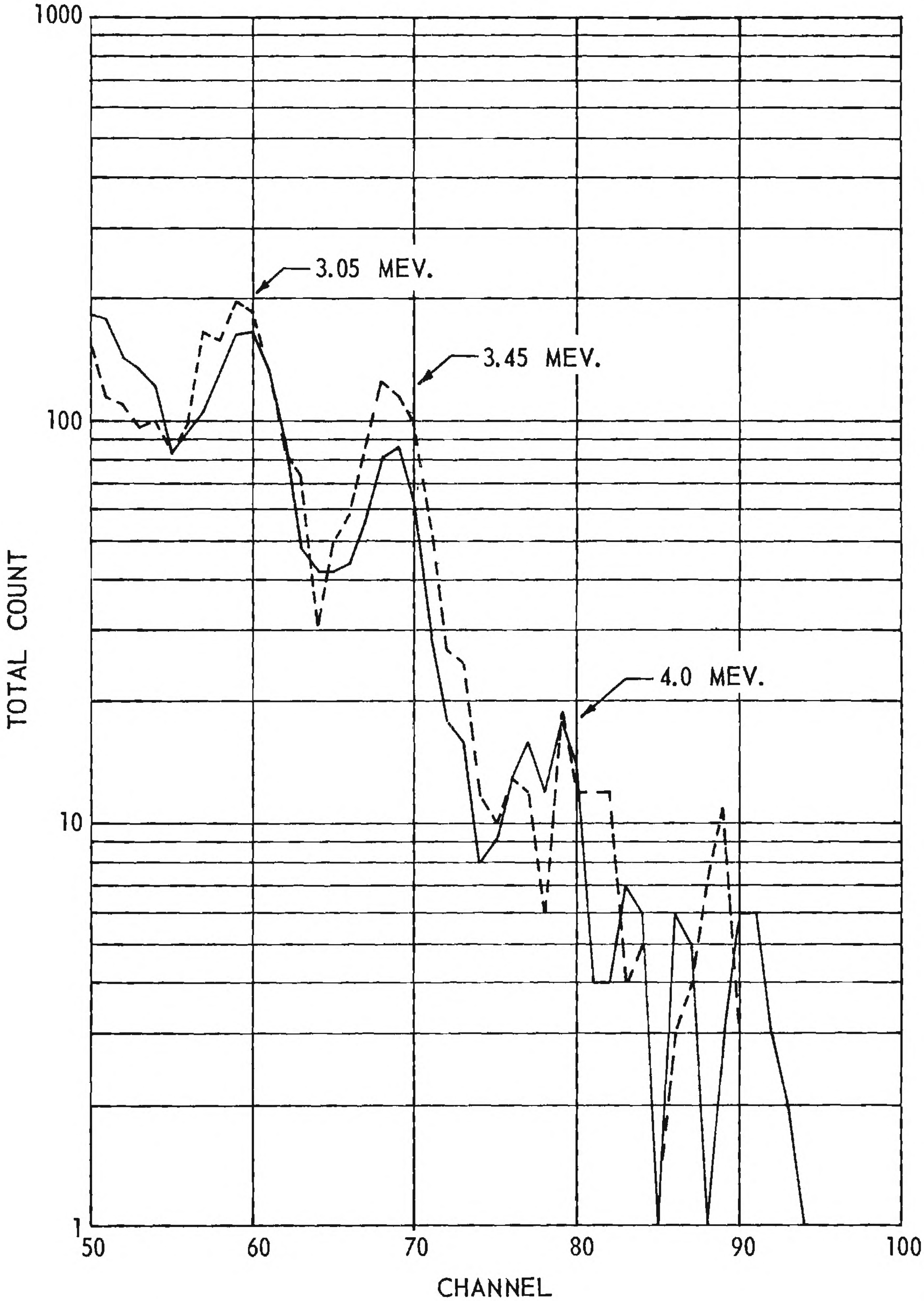


Figure 2 (Continued). Count Rate Versus Channel Number Obtained by Penco 100 Channel Analyzer.

III. FUTURE PROGRAM

During the summer of 1960 an active construction program will be in progress. Arrangements have been made with a selected number of producers to sample concrete made by them. Most of the activity during the summer will be concentrated on obtaining samples and testing of concrete to evaluate uniformity of mixing. The time following the testing program will be used for the analysis of results.

Respectfully submitted:

Donald O. Covault
Project Director

Approved:

Earl W. McDaniel
Co-Technical Director

Richard C. Palmer
Co-Technical Director

Wyatt C. Whitley
Co-Technical Director and Chief,
Chemical Sciences Division

QUARTERLY TECHNICAL STATUS REPORT NO. 3

PROJECT NO. A-446-7

DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT CONCRETE AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOISOTOPES

By

DONALD O. COVAULT

COVERING THE PERIOD
1 JUNE 1960 to 31 AUGUST 1960
Printed 10 September 1960

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UNITED STATES ATOMIC ENERGY COMMISSION
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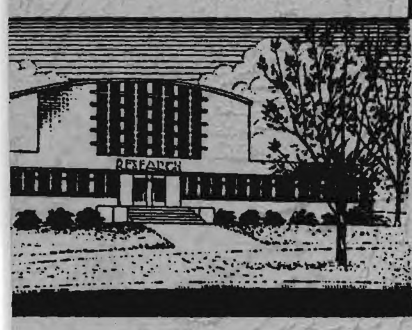
Performed for
UNITED STATES ATOMIC ENERGY COMMISSION
OFFICE OF ISOTOPES DEVELOPMENT
GERMANTOWN, MARYLAND



Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY TECHNICAL STATUS REPORT NO. 3

PROJECT NO. A-446-7

DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT CONCRETE AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOISOTOPES

By

DONALD O. COVAULT

COVERING THE PERIOD
1 JUNE 1960 to 31 AUGUST 1960
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AIKEN, SOUTH CAROLINA

Performed for
UNITED STATES ATOMIC ENERGY COMMISSION
OFFICE OF ISOTOPES DEVELOPMENT
GERMANTOWN, MARYLAND

ABSTRACT

A sampling and testing program to accumulate data by which the mixing uniformity of portland cement concrete may be determined has been in effect. One hundred fifty samples representing various mixing times from four mixes have been obtained and partially processed.

Strength cylinder and fineness modulus data from one plant in the Atlanta area indicates concrete strength to be dependent on mixing time and position in mixer.

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This report contains 4 pages.

Quarterly Technical Status Report No. 3, Project No. A-446-7

I. INTRODUCTION

The report summarizes the work performed on this project from June 1, 1960, to August 31, 1960. During the quarter, 150 samples were obtained from four concrete mixers to help determine the uniformity of mixing of portland cement concrete for various mix times.

II. DISCUSSION

A. Sampling and Processing

Two 1.26-cubic yard dual-drum highway pavers operating with a 10 per cent overload, a 3-cubic-yard horizontal tilting drum, and a 6-cubic-foot laboratory mixer were selected for sampling and evaluation as to mixing efficiency during this period. Three samples each were collected from batches which had been mixed 30, 45, 60, 120, and 180 seconds, respectively. The sampling process was replicated twice for the highway pavers and three times for the horizontal and laboratory drum mixers.

Each sample obtained was evaluated immediately by visual inspection for mixing adequacy; two mortar samples and a concrete strength cylinder were cast; and the remainder of the sample was used to determine the gradation of the aggregate in the mix.

B. Data

The following tables (I through II) present data accumulated from 45 samples of concrete taken at the MacDougald-Warren Hapeville Plant in Atlanta. This mixer has a 3-cubic-yard capacity and is classified as a horizontal tilting drum. Each batch sampled was theoretically identical in make-up, but the inaccuracy of weighing each constituent of the batch may account for the reduction in strength from the first to last replication. Chances for this type of error are rather remote, however.

TABLE I

28-DAY COMPRESSIVE STRENGTH IN POUNDS PER SQUARE INCH
OF CLASS "A" CONCRETE
MacDOUGALD-WARREN HAPEVILLE PLANT

Replication	Sample No.	Mixing Time (Seconds) 30	45	60	120	180
1	1	5850	5210	6230	5180	4730
	2	4210	4980	5210	4720	3980
	3	2650	4360	3880	3890	4330
2	1	5420	5050	5040	3830	3570
	2	5110	5370	4880	3300	2810
	3	3230	4220	3760	3600	3000
3	1	5390	6170	3220	3750	3270
	2	4380	4650	3040	3290	3390
	3	2190	3250	3220	2560	3000
Average Strength		4270	4810	4280	3790	3560

TABLE II

VARIATION IN SAMPLE STRENGTH IN POUNDS PER SQUARE INCH
DURING MIXER DISCHARGE
MacDOUGALD-WARREN HAPEVILLE PLANT

Sample No.	Replication	Mixing Time (Seconds) 30	45	60	120	180
1	1	5850	5210	6230	5180	4730
	2	5420	5050	5040	3830	3570
	3	5390	6170	3220	3750	3270
					Average Strength	4790
2	1	4210	4980	5210	4720	3980
	2	5110	5370	4880	3300	2810
	3	4380	4650	3040	3290	3390
					Average Strength	4220
3	1	2650	4360	3880	3890	4330
	2	3230	4220	3760	3600	3000
	3	2190	3250	3220	2560	3000
					Average Strength	3410

TABLE III

FINENESS MODULUS† MacDOUGALD-WARREN HAPEVILLE PLANT

Replication	Sample No.	Mixing Time (Seconds) 30	45	60	120	180
1	1	4.61	4.78	4.72	5.03	5.09
	2	5.09	5.05	5.09	5.01	4.96
	3	5.22	4.98	5.09	5.17	5.09
2	1	4.76	4.49	4.76	4.99	4.31
	2	5.01	4.85	5.05	5.07	5.17
	3	5.07	4.96	4.78	4.96	5.30
3	1	4.73	4.69	4.68	5.02	4.96
	2	5.00	4.91	4.94	5.15	5.08
	3	5.14	4.81	5.00	5.28	4.97
Average Fineness Modulus		4.96	4.84	4.90	5.08	4.99

†Fineness modulus is a numerical coefficient used to describe the sieve analysis of an aggregate. The percentage of material coarser than each sieve size is calculated and the sum of these percentages divided by 100 is the fineness modulus.

TABLE IV

VARIATION IN FINENESS MODULUS DURING MIXER DISCHARGE

Sample No.	Replication	Mixing Time (Seconds) 30	45	60	120	180
1	1	4.61	4.78	4.72	5.03	5.09
	2	4.76	4.49	4.76	4.99	4.31
	3	4.73	4.69	4.68	5.02	4.96
				Average Fineness Modulus		4.77
2	1	5.09	5.05	5.09	5.01	4.96
	2	5.01	4.85	5.05	5.07	5.17
	3	5.00	4.91	4.94	5.15	5.08
				Average Fineness Modulus		5.03
3	1	5.22	4.98	5.09	5.17	5.09
	2	5.07	4.96	4.78	4.96	5.30
	3	5.14	4.81	5.00	5.28	4.97
				Average Fineness Modulus		5.05

Table I indicates that length of mixing may affect the strength of concrete. Of particular interest (Table II) is the apparent decrease in average strength of concrete from the first to last portion of the batch as it is dumped from the mixer. Table IV apparently shows an increase in fine material in the aggregate or a decrease in fineness modulus, in the first portion discharged. These data may indicate a relationship between strength and aggregate size. Neutron activation of cast mortar samples to be performed during the next quarter is expected to show an increase in cement content in sample No. 1 for the various replications. The data presented above are subject to future statistical study before any valid conclusions may be drawn about significant factors in the experiment.

III. FUTURE PROGRAM

Two additional ready-mix concrete plants are scheduled for sampling during the fourth quarter. The Van de Graaff accelerator, to be used in cement content analysis of the mortar samples, will be made available to this project in several weeks and emphasis will be placed on processing mortar samples accumulated.

Approved:

Respectfully submitted:

Fred Sicilio
Co-Technical Director

Donald O. Covault
Project Director

Richard C. Palmer
Co-Technical Director

Wyatt C. Whitley
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Chemical Sciences Division

QUARTERLY TECHNICAL STATUS REPORT NO. 4

PROJECT NO. A-446-7

DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT CONCRETE AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOISOTOPES

By

DONALD O. COVAULT

COVERING THE PERIOD
1 SEPTEMBER 1960 to 30 NOVEMBER 1960
Printed 10 December 1960

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OFFICE OF ISOTOPES DEVELOPMENT
GERMANTOWN, MARYLAND

Engineering Experiment Station
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QUARTERLY TECHNICAL STATUS REPORT NO. 4

PROJECT NO. A-446-7

DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT CONCRETE AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOSOTOPES

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COVERING THE PERIOD
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OFFICE OF ISOTOPES DEVELOPMENT
GERMANTOWN, MARYLAND

ABSTRACT

The sampling program has been completed for the portland cement concrete mixers. The testing program is nearly complete. Most of the work during this quarter has been concerned with the development of a curve of cement content vs count rate and the analysis by neutron activation of cement content from these curves for samples taken in the program.

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Quarterly Technical Status Report No. 4, Project No. A-446-7

I. INTRODUCTION

This report summarizes research performed on this project from September 1, 1960, to November 30, 1960. The last concrete mixer in this program was sampled and activation analysis of known and unknown portland cement mortar samples was started. All conventional tests (i.e., visual evaluation of mixing, gradation analysis, and ultimate compressive strength) to evaluate the uniformity of concrete mixing have been completed. Nearly 400 concrete mortar samples must be activated with neutrons and analyzed to determine cement content. Activation analysis of these samples is about 75 per cent complete.

II. DISCUSSION

A. Sampling Program and Data Analysis

The sampling program was completed during this quarter. Five different portland cement concrete mixers were sampled in this experiment. Two of the mixers were 34E dual drum mixers that were being used on highway construction projects in the Atlanta area. The three remaining mixers were of stationary design and were used in concrete ready-mix plants in the Atlanta area. Each concrete mixer will be evaluated for uniformity of concrete for 30, 45, 60, 120, and 180 seconds of mixing. The mixing uniformity will be evaluated in terms of the following criteria:

(1) Visual evaluation of mixing adequacy.

(2) Gradation of aggregates in the concrete mixture as expressed by fineness modulus.

(3) Ultimate compressive strength of concrete cylinders.

(4) Cement content determination by neutron activation.

All data collected for these various tests are being evaluated by statistical procedures. Several variables which influence mixing, such as mixing time and position of the concrete in the mixer, and the interaction between these variables are being studied for each mixer type sampled in this research.

B. Neutron Activation of Cement Mortar

All cement mortar samples were activated in the one-million-volt Van de Graaff located in the Radioisotopes and Bioengineering Laboratory. The neutrons are produced by a beam of deuterons striking a beryllium target. This nuclear reaction is expressed by the following equation:

$$ {}_{4}Be^{9} + {}_{1}d^{2} \longrightarrow {}_{5}B^{10} + {}_{0}N^{1} $$

A flux of approximately 5×10^{6} neutrons per square centimeter second is produced by this reaction.

Approximately one per cent of the natural calcium is calcium 48. This isotope will react with a slow neutron in the following manner:

$$ {}_{20}Ca^{48} + {}_{0}N^{1} \longrightarrow {}_{20}Ca^{49} $$

$$ {}_{20}Ca^{49} \xrightarrow[\gamma]{\beta} {}_{21}Sc^{49} \xrightarrow[\gamma]{\beta} {}_{22}Ti^{49} $$

Ca^{49} has a half life of approximately 9 minutes. The gamma energies have some energy peaks above 2 Mev, and it is possible to determine the activity in the mortar sample caused by only the calcium because other radioactive isotopes produced by the neutron reaction have lower energies. The 3.07 Mev peak was used in this analysis.

Samples of concrete mortar containing known amounts of portland cement were activated in the Van de Graaff and the activity determined by a Penco 100 Channel Analyser for the 3.07 Mev peak.

Because of the variability of the flux produced by the Van de Graaff, an indium foil was activated with the mortar sample to provide a means of normalizing the cement count data. The data in Table I are an example of the information collected and computed in this analysis. Mortar samples of seven known cement contents were activated and counted. This procedure was replicated three times. The results of these experiments are shown by Figure 1. A linear equation determined for these data by regression analysis is shown in this figure. The correlation coefficient computed for these data is 0.997. This value indicates a very high correlation between cement content and count rate. The 95 per cent confindence limits for this curve have also been plotted and one can note that this value is approximately ± 0.075 gram of cement around a given point estimate determined from the curve.

III. FUTURE PROGRAM

All testing of samples, including activation of analysis, will be completed within a few weeks. After analysis of all data, the final report will be written. This report should be completed by February 1961.

Approved:

Respectfully submitted,

Fred Sicilio
Co-Technical Director

Donald O. Covault
Project Director

Richard C. Palmer
Co-Technical Director

Wyatt C. Whitley
Co-Technical Director and Chief,
Chemical Sciences Division

TABLE I

NEUTRON ACTIVATION ANALYSIS FOR SAMPLES OF PORTLAND CEMENT MORTAR
MACDOUGALD-WARREN MIXER
Hapeville, Georgia

	INDIUM FOIL ANALYSIS			PORTLAND CEMENT MORTAR SAMPLE ANALYSIS				
Sample No.	Weight W_f (Milligrams)	Counts Per Second* C'_f	Counts Per Second 20 Milligram: $\frac{C'_f \times 20}{W_f}$ C_f	Count Per 5 Minutes* (Channel 62-74) C'_c	Normalized Count $\frac{C'_c \times 300}{C_f} = C$ (300 is base of C_f)	Total Weight of Mortar W_m (Grams)	Cement Weight (From Figure 1 using value of C) W (Grams)	Cement Content (Gram Cement per gram Mortar) $\frac{W}{W_m}$ Per Gram
6	19.4	215	222	1099	1485	3.75	1.30	0.35
105	19.8	214	216	935	1299	4.17	1.13	0.27
78	22.2	279	251	844	1009	3.56	0.87	0.24
110	21.8	268	246	1328	1620	4.33	1.42	0.33
108	19.8	292	295	968	984	4.00	0.85	0.21
90	22.6	320	283	1027	1089	4.18	0.94	0.22
184	22.0	277	252	946	1126	3.95	0.98	0.25
145	25.6	360	281	994	1061	3.70	0.92	0.25
195	23.8	351	295	780	793	3.49	0.68	0.19
126	20.3	275	271	824	912	3.74	0.78	0.21
119	19.7	252	256	925	1084	3.99	0.94	0.24
125	21.7	316	291	736	759	3.58	0.65	0.18
140	21.0	295	281	850	907	3.79	0.78	0.21
137	20.2	318	315	1032	983	3.72	0.85	0.23
186	18.5	293	317	534	505	2.91	0.42	0.14

* Total count minus background count.

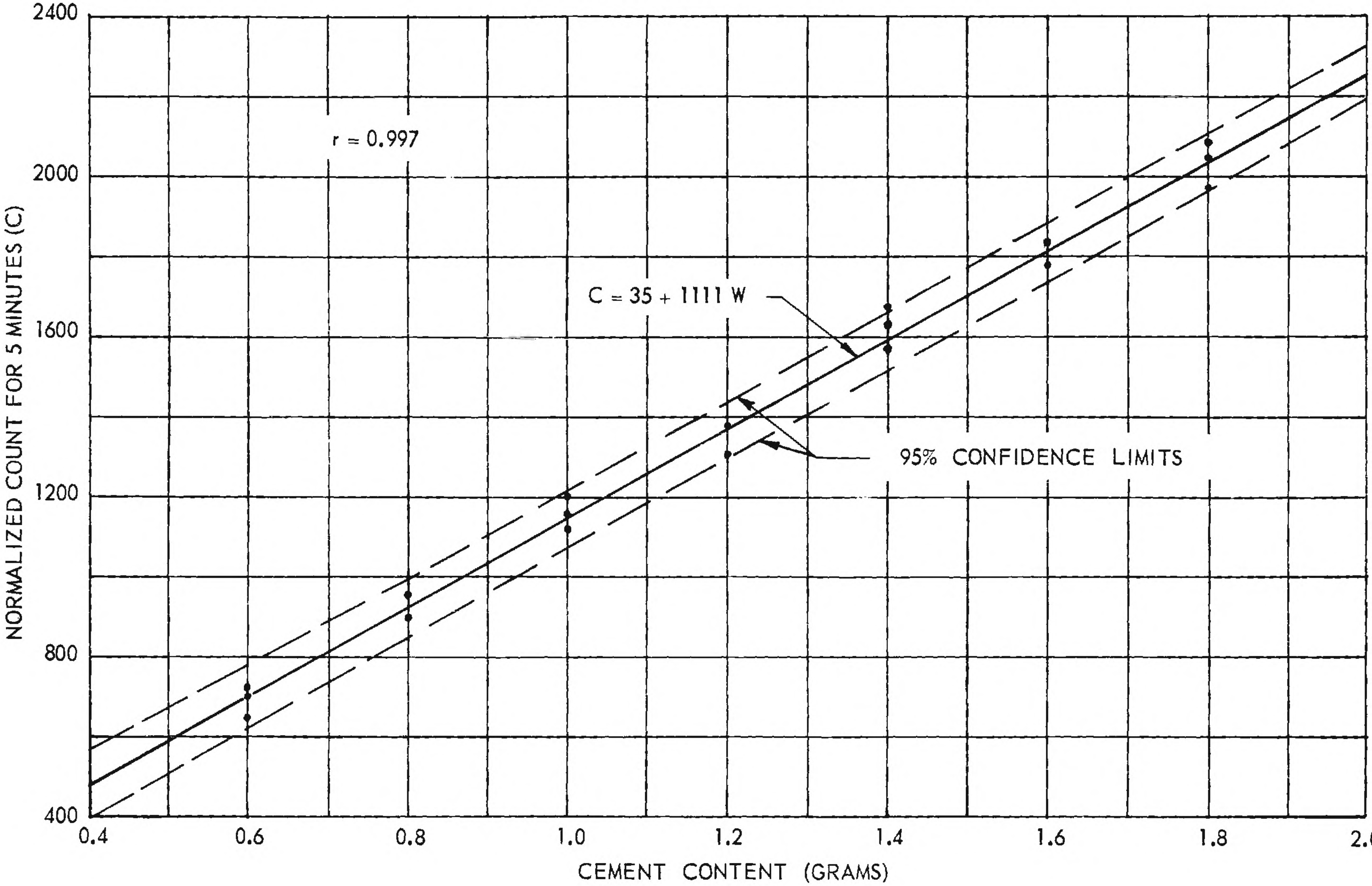

Figure 1. Cement Content Versus Count Rate Chart.

QUARTERLY TECHNICAL STATUS REPORT NO. 5

PROJECT NO. A-446-7

DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT CONCRETE AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOISOTOPES

By

DONALD O. COVAULT

COVERING THE PERIOD
1 DECEMBER 1960 to 28 FEBRUARY 1961
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OFFICE OF ISOTOPES DEVELOPMENT
GERMANTOWN, MARYLAND

Engineering Experiment Station
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QUARTERLY TECHNICAL STATUS REPORT NO. 5

PROJECT NO. A-446-7

DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT CONCRETE AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOISOTOPES

By

DONALD O. COVAULT

COVERING THE PERIOD
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UNITED STATES ATOMIC ENERGY COMMISSION
OFFICE OF ISOTOPES DEVELOPMENT
GERMANTOWN, MARYLAND

Quarterly Technical Status Report No. 5, Project No. A-446-7

ABSTRACT

All sampling and data analysis has been completed on this phase of the project. The final report is nearly completed and ready for review. A paper is being prepared for presentation before a national meeting next year.

Quarterly Technical Status Report No. 5, Project No. A-446-7

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This report contains 2 pages.

Quarterly Technical Status Report No. 5, Project No. A-446-7

I. INTRODUCTION

This report summarizes the work performed on this project from December 1, 1960, to February 28, 1961. Except for completion of some of the details of writing the final report and a paper for presentation before the Highway Research Board, all work on this phase of the project has been completed. A proposal for the continuation of the project is being submitted.

II. DISCUSSION

All analysis of data obtained from sampling operations performed upon five different concrete mixer designs was completed this quarter. These data were analyzed primarily by analysis of variance techniques to evaluate the significance of characteristics of mixer design and mixing time of portland cement concrete. Significance tests were made at the one and five per cent levels, and, although some significant differences were noted in cement content, fineness modulus, and compressive strength for the various mixers, definite relationship about mixer design or time of mixing could not be established.

Cement content was obtained by neutron activation analysis. This method proved to be entirely feasible and reliable. Cement content could be predicted to within approximately 0.07 grams, 95 per cent of the time for the mortar samples used in these experiments.

The final report is nearly completed and will be submitted for review within a few weeks. A paper on the determination of cement content by neutron activation is being prepared for presentation before the Highway Research Board in January 1962. This paper will be completed by the end of the month of March and will be submitted for approval.

III. FUTURE PROGRAM

A proposal will be submitted on this project to cover the mixing problems associated with bituminous concrete. Because of the different physical and chemical nature of bituminous materials from portland cement, the application of nuclear energy techniques to the determination of the characteristics of the bituminous mixture must be studied in a different manner than that used for portland cement.

Respectfully submitted:

Donald O. Covault
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Approved:

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QUARTERLY TECHNICAL STATUS REPORT NO. 6

PROJECT NO. A-446-7

DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT CONCRETE AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOISOTOPES

By

DONALD O. COVAULT

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OFFICE OF ISOTOPES DEVELOPMENT
GERMANTOWN, MARYLAND

ABSTRACT

Changes in the submitted annual report in conformity with the comments and suggestions of the Office of Isotopes Development are now being made. Investigation of the equipment requirements and procedures needed for the determination of the mixing quality of bituminous concrete is now under way. Revision of existing equipment to use materials as required by the Office of Isotopes is necessary. A request for these additional funds has been submitted. The personnel necessary to adequately carry out the research required under the contract extension have been employed.

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This report contains 3 pages.

I. INTRODUCTION

This report summarizes the work performed on this project from March 1 to June 30, 1961. The annual report covering the research activities for the first year has been submitted for review. Comments associated with this review were received recently, and the report is being revised in conformity with comments contained in this review. Work is also proceeding on the second phase of the work dealing with the development of nuclear techniques for the evaluation of the mixing problems associated with bituminous concrete.

II. DISCUSSION

A. Revision of Annual Report

A review of the annual report of this project was made by the Office of Isotopes Development. This report covered the activities for the first phase of this work dealing with application of radioisotopes to ascertain the mixing quality of portland cement concrete. This report is now being revised in conformity with the comments and suggestions contained in the review.

A paper is also being prepared from this report for possible presentation at the annual meeting of the Highway Research Board in January 1962. The paper will be published in the proceedings of this meeting.

B. Investigation of the Uniformity of Bituminous Concrete

The equipment requirements and procedures for the second phase of this work dealing with the mixing problems of bituminous concrete are now being investigated. The Van de Graaff is being considered as a tool for neutron activation of the constituents of bituminous concrete. The neutrons will be produced by deuterons striking a tritium target. The use of a gauge to measure neutron backscatter from a radioactive source for the determination of asphaltic content is under study and investigation.

Because the production of neutrons must be accomplished by materials which fall under the scope of the Office of Isotopes Development, revision of the existing equipment is necessary to use these materials. Total estimated costs of a tritium target, shielding, and moderator revision, and an Ac-Be or Pu-Be neutron source for the neutron backscatter gauge, are $2,800.00. A letter to Mr. Oscar Bizzel has recently been submitted requesting these additional funds.

C. Personnel

The services of Drs. Richard C. Palmer and D. W. Martin were used to help develop the feasibility of some methods anticipated for use on this project. Mr. Paul Howard, who plans to work for the master's degree in Civil Engineering, will be employed in the Fall 1961 on this project.

D. Expenditures

Expenditures have been small in the past quarter primarily because most of the work has been concerned with library research and preliminary studies. Furthermore, a substantial portion of time during this period was spent in completing and revising the annual report.

III. FUTURE WORK

The investigation of equipment and procedure requirements for carrying out the program to evaluate the mixing quality of bituminous concrete will be continued during the next quarter. A preliminary study of the source strength required to effectively measure asphalt content by neutron backscatter will be made in addition to the most feasible gauging system for this purpose. The most feasible method of the determination of fine aggregate portion of bituminous concrete using neutron activation will also be considered.

Respectfully submitted:

Donald O. Covault
Project Director

Approved:

Fred Sicilio
Co-Technical Director

Richard C. Palmer
Co-Technical Director

Wyatt C. Whitley
Co-Technical Director and Chief,
Chemical Sciences Division

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY TECHNICAL STATUS REPORT NO. 7

PROJECT NO. A-446-7

DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT CONCRETE AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOISOTOPES

By

DONALD O. COVAULT

COVERING THE PERIOD
1 JULY 1961 to 30 SEPTEMBER 1961
Printed 10 October 1961

CONTRACT NO. AT (38-1)-202
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Placed By
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AIKEN, SOUTH CAROLINA

Performed for
UNITED STATES ATOMIC ENERGY COMMISSION
DIVISION OF ISOTOPE DEVELOPMENT
GERMANTOWN, MARYLAND

ABSTRACT

The annual report has been submitted to the Division of Isotope Development. The neutron shield for the Van de Graaff is being constructed and should be completed during the month of October. Sample size dimensions for neutron backscatter measurements to determine asphaltic content of bituminous concrete are being studied. Additional personnel to help performed work required on this project has been obtained.

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This report contains 2 pages.

Quarterly Technical Status Report No. 7, Project No. A-446-7

I. INTRODUCTION

This report summarizes the work performed on this project from July 1, 1961 to September 30, 1961. The revised annual report has been completed, and submitted. A research assistant has been employed to help conduct the work involved in the second phase of this work dealing with mixing uniformity of bituminous concrete. The neutron shield for the Van de Graaff is being constructed and the feasibility of using a commercial neutron backscatter gauge for asphaltic content determination of bituminous concrete is being investigated.

II. DISCUSSION

A. Annual Report

The annual report covering the mixing uniformity of portland cement concrete has been submitted to the Division of Isotope Development. The revisions suggested by this agency have been completed and incorporated into this report.

A paper to be presented to the Highway Research Board on the work contained in the Annual Report is nearly prepared for presentation at the annual meeting in Washington, D. C., January, 1962.

B. Investigation of the Uniformity of Bituminous Concrete

An investigation of the size of sample required to measure the asphaltic cement content of a bituminous concrete mixture using neutron backscatter is now underway. The d-M gauge developed and sold by the Nuclear Chicago Corporation is being used for this purpose. The neutron shield for the Van de Graaff is 30 per cent completed and will be finished during the month of October.

A sampling program is now being considered using bituminous concrete produced for highway paving projects in the Atlanta area as sources of samples.

Samples of material produced in the laboratory will also be evaluated. The asphaltic content of bituminous concrete will be determined by neutron backscatter and the distribution of the fine aggregate (mineral filler) will be determined by neutron activation. Samples of material for neutron activation of the fine aggregate similar to the cement samples used in the portland cement phase of this work are planned to be used.

C. Personnel

Mr. Paul Howard who plans to work on for the master's degree in Civil Engineering has been employed on this project. One student assistant who will help Mr. Howard has also been employed.

III. FUTURE WORK

The development of a testing program, completion of the neutron shield and the determination of size of sample for neutron backscatter measurements will be performed during the next quarter.

Respectfully submitted:

Donald O. Covault
Project Director

Approved:

Richard C. Palmer
Co-Technical Director

Wyatt C. Whitley
Co-Technical Director and Chief
Chemical Sciences Division

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY TECHNICAL STATUS REPORT NO. 8

PROJECT NO. A-446-7

DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT CONCRETE AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOISOTOPES

By

DONALD O. COVAULT

COVERING THE PERIOD
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Performed for
UNITED STATES ATOMIC ENERGY COMMISSION
DIVISION OF ISOTOPE DEVELOPMENT
GERMANTOWN, MARYLAND

ABSTRACT

The neutron moderator for the Van de Graaff has been completed and installed. Investigation to determine minimum sample size dimensions for neutron backscatter measurements to determine asphaltic content of bituminous concrete is in progress. The water shield for the Van de Graaff is under construction.

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This report contains 2 pages.

I. INTRODUCTION

This report summarizes the work performed on this project from October 1, 1961, to December 31, 1961. The neutron moderator for the Van de Graaff has been completed and installed and a cooling system for the tritium target is being installed. Work is progressing on the water shield for the Van de Graaff. Feasibility of using a commercial neutron backscatter gauge for asphaltic content determination of bituminous concrete is being investigated.

II. DISCUSSION

A. Investigation of the Uniformity of Bituminous Concrete

Sample size dimensions required for infinite size for the determination of asphaltic content of bituminous concrete mixture using neutron backscatter is under study. Results obtained using the Model P-21 moisture probe developed by the Nuclear Chicago Corporation indicate that approximately 10 inches is equivalent to infinite thickness. Initial tests conducted on a 4-inch-thick sample indicate minimum sample dimensions are 19 inches long and 19 inches wide. Investigation to determine the effect of thickness on minimum length and width of sample is still in progress.

The neutron moderator for the Van de Graaff was completed and installed with the tritium target holder in place. The target holder has since been removed and stored as a safety precaution.

B. Personnel

The services of Dr. Richard C. Palmer as technical advisor to the project are no longer available to the project because Dr. Palmer terminated employment with Georgia Tech on December 23, 1961. Mr. Paul Howard is now

Graduate Research Assistant on the project. Mr. Howard recently received the Bachelor of Science Degree in Civil Engineering from Georgia Tech.

III. FUTURE WORK

The development of a testing program, completion of the water shield for the Van de Graaff, and completion of the determination of minimum size of sample to determine asphaltic content of bituminous concrete using neutron backscatter measurements will be performed during the next quarter.

Respectfully submitted:

Donald O. Covault
Project Director

Approved:

Wyatt C. Whitley
Co-Technical Director and Chief,
Chemical Sciences Division

QUARTERLY TECHNICAL STATUS REPORT NO. 9

PROJECT NO. A-446-7

DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT CONCRETE AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOISOTOPES

by

DONALD O. COVAULT

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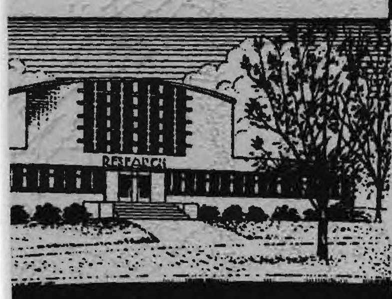
DIVISION OF ISOTOPES DEVELOPMENT
GERMANTOWN, MARYLAND



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of the Georgia Institute of Technology
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QUARTERLY TECHNICAL STATUS REPORT NO. 9

PROJECT NO. A-446-7

DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT CONCRETE AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOISOTOPES

By

DONALD O. COVAULT

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Performed for
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DIVISION OF ISOTOPES DEVELOPMENT
GERMANTOWN, MARYLAND

ABSTRACT

A paper was presented at the Highway Research Board Meeting in January 1962 on the major findings of this project dealing with portland cement concrete. The use of neutron backscatter to determine the asphaltic content of bituminous mixtures that have been placed in relatively thin layers was not found to be feasible. Standard samples so that a count rate versus numeral filler content graph can be determined are now being made. Plans are also being made to sample laboratory and commercial mixes during the coming quarter.

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This report contains 2 pages.

I. INTRODUCTION

This report summarizes the work performed on this project from January 1, 1962, to March 31, 1962. Work during this period has been primarily concerned with the development of the procedures and testing program required for the determination of mineral filler distribution in a bituminous concrete mixture using neutron activation.

This contract has been recently extended nine months and will terminate on December 31, 1962 instead of the original date of March 31, 1962. No additional funds will be required in this extension. However, an additional $2800 that was authorized for expenditure in July 1961 will be added to the contract because these funds were not added when authorized in July 1962.

II. DISCUSSION

A. Paper Presented at the Highway Research Board Meeting

A paper entitled "Use of Neutron Activation Analysis to Determine the Cement Content of Portland Cement Concrete," was presented at the annual meeting of the Highway Research Board on January 9, 1962. This paper covered the major findings of this project dealing with portland cement concretes.

B. Investigation of Feasibility of Using Neutron Backscatter to Determine Asphaltic Content of Bituminous Mixtures

A thorough investigation of the possibilities of using neutron backscatter to determine the asphaltic content of bituminous mixtures indicates that this method was not feasible when the bituminous mixture was placed in thin layers (from 2 to 3 inches in depth). Direct attenuation methods to measure asphaltic content, however, are feasible. The use of these methods will require that all tests must be performed at the plant where the bituminous mixture is produced, and these methods can not be used on the pavement in place.

C. Analysis of the Mineral Filler in the Bituminous Mixture

Investigations are now being made to determine the feasibility of using neutron activation to determine the mineral filler content of bituminous concrete using results obtained in prior experiments performed on portland cement samples. A sample size of 0.75 inch in diameter and 0.75 inch high was determined for activation analysis for the bituminous concrete. This size was based on the neutron flux produced by the tritium target in the Van de Graff and the amount of calcium-49 that will be produced in the numeral filler when activated by neutrons. Standard samples containing known amounts of mineral filler are now being made so that a count rate versus mineral filler content graph can be determined. This chart will cover the range of mineral filler found in the usual bituminous concrete mixtures.

III. FUTURE WORK

Work during the next quarter will be concerned with the development of the count rate versus mineral filler content curve for bituminous concrete. Some sampling of laboratory and commercial mixers is also planned during this period.

Respectfully submitted:

Donald O. Covault
Project Director

Approved:

Wyatt C. Whitley, Chief
Chemical Sciences Division

QUARTERLY TECHNICAL STATUS REPORT NO. 10

PROJECT NO. A-446-7

DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT CONCRETE AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOISOTOPES

By

DONALD O. COVAULT

COVERING THE PERIOD
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GERMANTOWN, MARYLAND

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Atlanta, Georgia

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY TECHNICAL STATUS REPORT NO. 10

PROJECT NO. A-446-7

DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT CONCRETE AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOISOTOPES

By

DONALD O. COVAULT

COVERING THE PERIOD
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DIVISION OF ISOTOPES DEVELOPMENT
GERMANTOWN, MARYLAND

Quarterly Technical Status Report No. 10, Project No. A-446-7

ABSTRACT

Sampling and construction of test specimens was completed. The Van de Graaff Generator target was changed from Tritium to Beryllium because of safety requirements and the low neutron flux density produced by the Tritium target. The next quarter will be devoted to testing and analysis of test results. A proposal will be prepared for developing a gauge to measure asphaltic content of bituminous mixtures.

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This report contains 2 pages.

Quarterly Technical Status Report No. 10, Project No. A-446-7

I. INTRODUCTION

This report summarizes the work performed on this project from April 1, 1962 to July 31, 1962. During this period the work has involved collection of samples, construction of test specimens and preparation for neutron activation.

As a result of a June meeting in Washington, the present project work will be concluded as soon as possible so that work to develop a gauge to measure asphaltic content of bituminous mixtures can begin.

II. DISCUSSION

A. Sampling and Test Specimens

The Georgia Tech Laboratory mixer and the hot mix plant owned by McIntosh Paving Company in Tyrone, Georgia, were sampled in accordance with the requirements of the split-plot design of this experiment. Further field sampling dates were canceled as the result of a meeting on June 8, 1962, held in the Atomics Building in Washington with members of the Atomic Energy Commission and the Bureau of Public Roads. The consensus of the meeting was that present work be concluded as soon as possible and that work be started to develop a gauge to measure asphaltic content of bituminous mixtures.

Specimens for Hveem Stability, gradation analysis and neutron activation analysis were constructed and testing has started.

B. Neutron Activation Analysis

The Tritium target for the Van de Graaff Generator was installed and all systems were operative. A pilot run was conducted on July 25, 1962.

The Bremsstrahlung Gamma radiation count of the tritium target, just before and just after the pilot run, was used as an indication of the loss of tritium from the target during the run. This loss, when calculated, was slightly below the allowable yearly average for discharging tritium into the atmosphere. Because this loss was so high Robert L. Zimmerman, the Radiological Safety Officer of Georgia Tech, recommended that no more tritium be discharged into the atmosphere.

Along with the loss of Tritium from the target, there was a decrease in thermal neutron flux density at the specimen. This decrease was measured by counting an Indium foil which was placed under the specimen during radiation. The Indium foil count rate decreased 50 per cent during the cumulative 90 minute beam-on-target period of the 3 hour pilot run. The lower neutron flux density was insufficient to produce a statically reliable Ca^{49} count rate.

Because of the dual problem of the loss of Tritium from the target which would produce short target life and the low neutron flux density at the specimen, the decision was made to switch from the Tritium target to a Beryllium target. The Beryllium target has been installed and neutron activation will commence.

III. FUTURE WORK

Work during the next quarter will consist of testing and statistical analysis of testing and statistical analysis of test results. A proposal will be prepared for the development of a gauge for measuring the asphaltic content of bituminous mixtures.

Respectfully submitted:

Donald O. Covault FB.
Project Director

Approved:

Frederick Bellinger, Chief
Chemical Sciences and Materials Division

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

QUARTERLY TECHNICAL STATUS REPORT NO. 11

PROJECT NO. A-446-7

DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT CONCRETE AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOISOTOPES

By

DONALD O. COVAULT

COVERING THE PERIOD
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AIKEN, SOUTH CAROLINA

Performed for
UNITED STATES ATOMIC ENERGY COMMISSION
DIVISION OF ISOTOPES DEVELOPMENT
GERMANTOWN, MARYLAND

ABSTRACT

Neutron activation and all data collection are complete. Data reduction and analysis has started. The Rich Electronic Computer Center will do part of the required computations.

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This report contains 2 pages.

I. INTRODUCTION

This report summarizes the work performed on this project from August 1, 1962, to September 30, 1962. During this period the collection of all data was completed and analysis of data was started.

II. DISCUSSION

A. Neutron Activation

Neutron activation was started at the beginning of this report period using a Beryllium target. The use of helium gas in the Van de Graaff for another experiment produced progressive ion source tube failure and resulting neutron flux instability. Work on this project was suspended until the ion source tube could be replaced. After replacement of the tube, the work was completed using a beam of 48 microamperes at 1.0 M.E.V.

B. Data Analysis

Regression analysis is underway to determine the relationship between count rate and mineral filler. Analysis of variance will also be made to determine the effects of mixing time, position, and replication or their interactions on dispersion of mineral filler in the bituminous mix. Similar analyses will be made to determine the effects of mixing time, position, and replication or their interactions on Hveem stability and gradation for field and lab mixers. A portion of the required computations will be done by Rich Electronic Computer Center.

III. FUTURE WORK

Future work will be the completion of the analyses and preparation of a final project report.

Respectfully submitted:

Donald O. Covault
Project Director

Approved:

Frederick Bellinger, Chief
Chemical Sciences & Materials Division

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA 13, GEORGIA

January 7, 1963

U. S. Atomic Energy Commission
1717 H Street, N.W.
Washington 25, D. C.

Attention: Dr. Paul C. Aebersold, Director
Division of Isotopes Development

Subject: Quarterly Technical Status Report No. 12, Project No. A-446-7
"Determination of the Uniformity of Mixing of Portland Cement Concrete and Bituminous Concrete for Various Mixing Times by the Use of Radioisotopes"
Contract No. AT (38-1)-202, Task No. VII
Covering the Period from October 1 to December 31, 1962

Gentlemen:

Analyses of all data has been completed. The final project report is complete in rough form and is being prepared for reproduction. This report will be submitted about January 20, 1963.

Respectfully submitted:

Donald O. Covault
Project Director

Approved:

Frederick Bellinger, Chief
Chemical Sciences & Materials Division

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DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOISOTOPES

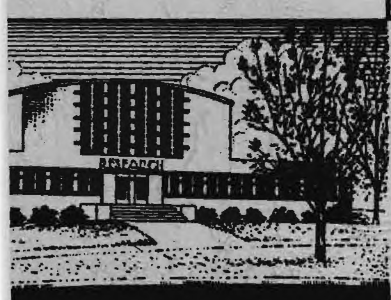
(Final Technical Report for That Phase of the Program Dealing with Portland Cement Concrete)

By

CLYDE POOVEY and DONALD O. COVAULT

Performed for
THE OFFICE OF ISOTOPES DEVELOPMENT
UNITED STATES ATOMIC ENERGY COMMISSION

APRIL 20, 1961



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ANNUAL REPORT NO. 1

PROJECT NO. A-446-7

DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOISOTOPES

(Final Technical Report for That Phase of the Program Dealing with Portland Cement Concrete)

By

CLYDE POOVEY and DONALD O. COVAULT

COVERING THE PERIOD
1 DECEMBER 1960 to 31 MARCH 1961
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AIKEN, SOUTH CAROLINA

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OFFICE OF ISOTOPES DEVELOPMENT
GERMANTOWN, MARYLAND

ABSTRACT

Many millions of dollars are spent each year by the construction industry for portland cement concrete. This concrete is produced by a variety of concrete mixer designs and varies in specified quality from low strength concrete used in unstressed members to very high strength concrete used in prestressed and reinforced concrete construction. Uniformity of mixing is a good criterion by which to judge the quality of the concrete mix and mixing adequacy. In this research, cement content of mortar, fineness modulus of the aggregate, ultimate compressive strength, and visual inspection of mixing quality were used to indicate the uniformity of the mixed concrete. With the exception of cement content, all determinations of the physical characteristics of the concrete were made by conventional tests as specified by the American Society of Testing Materials.

Cement content of the concrete mortar was determined by neutron activation analysis of calcium-49 produced in the calcium in the portland cement. This method of cement content determination proved very feasible and could be used to predict the cement content within approximately 10 per cent of its true value 95 per cent of the time.

Mixing time, batch replication, and position in the concrete mixer generally did not have significant effect upon cement content, fineness modulus, and compressive strength for mixers studied. Mixing times (exclusive of charging, transfer, and discharging) varying from 30 to 180 seconds were used in evaluating uniformity of mixing.

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I. INTRODUCTION

A. General Remarks

During the past 2 years, approximately 800 million barrels of cement have been produced for use in every area of construction work. Of this 800 million barrels, 52 per cent were shipped to ready-mix plants. It is estimated that 130 million cubic yards of ready-mixed concrete was produced in each of the last 2 years at a cost of over 3.5 billion dollars.

Typical news releases during the past year are as follow:

1. "North Carolina has 171.7 miles of concrete paving underway."
2. "46 million dollars bond issue just passed for concrete expressway near Miami, Florida."
3. "Work has started on a 12 million dollars reinforced concrete bridge for an interchange connecting four freeways in East Los Angeles."
4. "Dulles International Airport, Chantilly, Va. 100 million dollars airport is designed with concrete runways, aprons, and roads."

B. Testing Methods to Determine Mixing Uniformity

One of the most important characteristics which control the quality of portland cement concrete is the uniformity of mixing. Adequately mixed, portland cement concrete exhibits such desirable qualities as optimum strength, workability, and durability. Because of the demand for concrete in building and road construction, it has become increasingly important to develop some simple method for the evaluation of mixing efficiency.

Manufacturers of concrete mixers are interested in evaluating the mixing efficiency of mixers having different speeds of rotation, different shapes, different blade sizes, and different blade angles. Producers of ready-mixed concrete are interested in securing a uniform mix in the minimum mixing time; state highway departments and other users of concrete are interested in obtaining concrete having optimum strength and durability from plants supplying concrete for buildings, bridges, and highways.

Concrete mixers of various designs range in size from 1.5 cubic feet to 10 cubic yards. Common designs in use at central batch plants are the turbine mixer, horizontal tilting drum, and the nontilting horizontal drum. The principal mixer used in concrete highway paving is the 34-E dual drum paver.

With a knowledge of the minimum time required for a specific mixer to produce concrete having a uniform dispersion of aggregate and cement throughout the mix, mixing time may well be reduced from the conventional time required by present specifications. This reduction should result in increased capacity and lower production costs with no sacrifice in quality.

Many tests may be run on samples of fresh concrete selected from a mixer to help evaluate mixing efficiency. To determine the uniformity of a concrete mix, samples from various positions can be compared for their air content, moisture content, modulus of rupture, fineness modulus of aggregate, compressive strength, usual appearance for mixing adequacy, and cement content. It was not feasible in this research to run each of these tests because of time and money considerations; therefore, the last four tests were selected to evaluate mixing efficiency.

Essentially two methods were available to evaluate cement content using radioactive isotopes. One method consists of adding a radioactive tracer to the cement prior to mixing in the concrete mass. The cement and tracer are mixed in the concrete by the mixing equipment and samples of the cement mortar are then evaluated for radioactivity caused by the tracer. Low variance in activity of the tracer for various points in the mix indicates relative uniformity in mixing of the cement and high variance indicates poor uniformity in mixing. Several isotopes, such as silicon-31, sodium-24, gold-198 or the activated cement itself, could be used as tracers for this procedure.

When mixed with quantities of cement used in the conventional concrete mixers, the use of tracers present serious problems. Approximately 500 pounds of cement are used with each batch of concrete in a mixer with a one cubic-yard capacity. Mixing a tracer uniformly in this quantity of cement is very difficult. In attempting to evaluate uniformity, therefore, two mixing problems are present: the mixing of the tracer with the cement and the mixing of the cement with the aggregates and water in the concrete batch. Furthermore, a large quantity of dust is created in the mixing operation and would create a serious safety hazard if it contained radioactive material.

The second method consists of irradiation with neutrons of samples of cement mortar which are removed from various points in a wet concrete mass. The amount of activity present in the irradiated sample will be proportional to the cement content. This irradiation can be accomplished by using a radioactive source which produces neutrons, by using a reactor, or by using an accelerator.

Neutron activation analysis was used in this research to determine cement content. Cast samples of portland cement mortar were activated in a neutron source. The amount of radioactivity produced in the sample of mortar was proportional to its cement content. A curve was produced by determining the count rate for cement mortar samples containing various known weights of cement. The unknown weight of cement contained in any mortar sample was determined by activating an isotope of calcium in the sample in a neutron source, counting the activity, and determining the cement content from the cement content versus count-rate curve.

Various methods have been devised in the past for determining the cement content in a sample of concrete. The most prevalent method consists of determining the amount of soluble silica and calcium oxide in a sample by chemical analysis, and then indirectly calculating the percentage of cement by assuming some definite values of calcium oxide and silica in the cement.[1] The method was devised for determining the cement content of a large sample of concrete, but can be used equally well in processing small mortar samples. This method is time consuming, requires a well-equipped laboratory with trained personnel, and is not applicable to concrete containing aggregates such as slag, diatomites, and sodium silicates which liberate soluble silica under test conditions.

W. M. Dunagan suggest a test intended for use in the field for determining, prior to the initial hardening, the constituents of concrete.[2] According to this method, the sample is first weighed in air and then weighed in water and finally washed over a number 100 sieve. The aggregate is again weighed in water and the immersed weight of cement is obtained by the difference in the two submerged weights. It is necessary to know the specific gravity of cement to calculate its weight in air. An appreciable error enters the calculations in the assumption that all material passing the number 100 sieve is cement.

Another procedure for determining the cement content of a sample of freshly mixed concrete consists of using a heavy liquid and a centrifuge process for separating cement from the other ingredients of concrete.[3] The heavy media used comprises a liquid mixture of which the specific gravity may be adjusted to a value intermediate between that of cement and fine aggregate, thereby permitting

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[1] "Standard Method of Test for Cement Content of Hardened Portland Cement Concrete," Manual, A.S.T.M., Part IV, 1958.

[2] W. M. Dunagan, "A Study of the Analysis of Fresh Concrete," Proceedings, A.S.T.M., Vol. 31, Part I, 1931, pp. 362-386.

[3] W. G. Hime and R. A. Willis, "A Method for the Determination of Cement Content of Plastic Concrete," Bulletin No. 209, A.S.T.M., Oct. 1955, pp. 37-43.

the cement to sink and the aggregate to float. By means of appropriate calibration curves, cement content may be estimated.

The basis of a method by L. J. Murdock is the determination of the specific gravity of a cement suspension.[4] After washing a sample of fresh concrete over a number 100 sieve, hydrometer readings are recorded of the suspension collected. By reference to a control curve obtained from hydrometer readings of water in which known quantities of cement are suspended, the amount of cement can be determined. Here again, the assumption that all material passing through the number 100 sieve is cement creates an appreciable error in the calculations.

Two additional methods for determining cement content were developed by L. R. Chadda.[5] In the first method, cement content is estimated by a conductimetric method based upon the determination of conductivity of pure water in which known quantities of unset cement-sand mixture have been shaken. From a standard curve showing the relationship between cement concentration and conductivity, the cement content of a sample can be interpolated from its conductivity measurement. Chadda's other method for determining cement content is based upon the differential absorption characteristics of cement and sand particles. The per cent absorption increases as the concentration of cement increases in the mixture.

The latter two methods can be satisfactorily employed only for the determination of cement content in a freshly prepared cement-sand mixture to which no water has been added.

Previous research in this field has been primarily concerned with methods for spot checking samples of fresh concrete to insure a contractor's adherence to design specifications as to the amount of cement present. To this date, no

[4] L. J. Murdock, "The Determination of the Properties of Concrete," Cement and Lime Manufacture, Vol. 21, 1958, pp. 91-96.

[5] L. R. Chadda, "The Rapid Determination of Cement Content in Concrete and Mortar," Indian Concrete Journal, Vol. 29, No. 8, Aug. 1955, pp. 258-260.

attempt has been made to determine the uniformity of cement dispersion throughout the concrete mix. One of the purposes of this research was to develop a method which will enable manufacturers of mixers, producers of ready-mixed concrete, and users of concrete to investigate the distribution of cement in a mixer operating under a given set of conditions, thereby allowing the optimum mixing time and operating characteristics of machinery design to be determined. In evaluating mixing efficiency, a sampling program and a rapid and accurate method for determining cement content of mortar samples will be developed.

II. EQUIPMENT FOR ACTIVATION ANALYSIS

A. Van de Graaff Accelerator

Activation of cast mortar samples was accomplished through the use of Georgia Tech's one-million-volt Van de Graaff positive ion accelerator (made by the High Voltage Engineering Corporation).

The Van de Graaff is a special type of electrostatic accelerator which has a highly insulated terminal and a means of maintaining the terminal at a very high static potential with respect to ground. An ion injected into the high potential end of the machine is accelerated and directed by the electrostatic field downward through an evacuated acceleration tube to ground.

As an ion source, a mixture of ordinary and heavy hydrogen (deuterium) is used, which gives a beam containing about 25 microamperes each of protons and deuterons. The 25-microampere mixed beam of deuterons and H_2^+ ions at one million electron volts is directed through the evacuated tube onto a target of beryllium metal to produce the reaction

$$_4Be^9 + {}_1d^2 \rightarrow {}_5B^{10} + {}_0n^1 + \text{energy.}$$

A small general-purpose thermal neutron moderator as shown in Figure 1 was constructed for use with the Van de Graaff in performing this project. The beryllium target is surrounded by a mass of paraffin having an aluminum sleeve

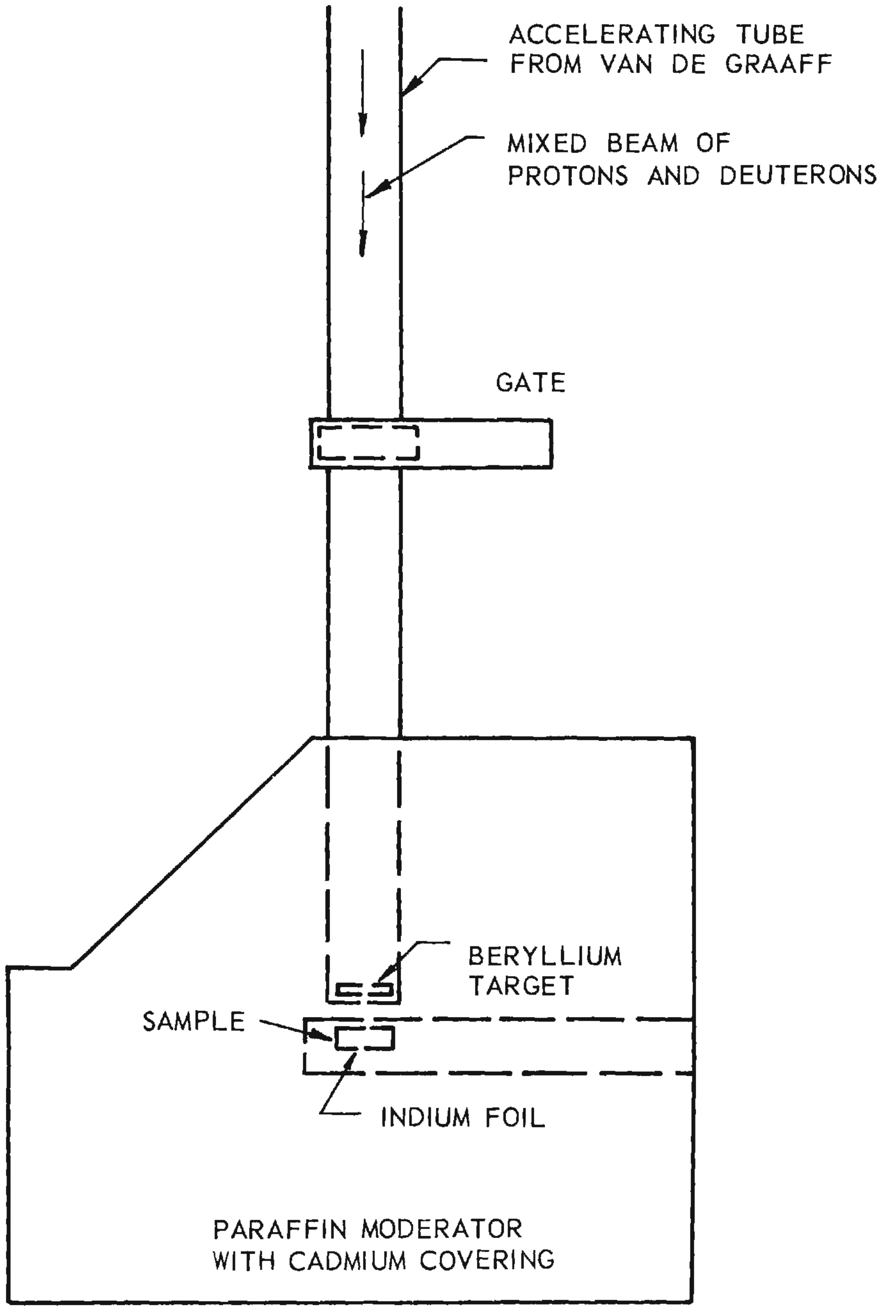

Figure 1. Thermal Neutron Moderator and the Van de Graaff.

for positioning the mortar samples several centimeters below the target. The thermal neutron flux at the sample position was of the order of 5×10^6 thermal neutrons per square centimeter per second.

The purpose of the paraffin is to thermalize the fast neutrons, thereby permitting their capture by the Ca^{48} atoms. The cadmium shield merely prevents the escape of thermal neutrons from the irradiator. Figure 2 is a photograph of the neutrons irradiator situated in the Van de Graaff.

B. Other Methods of Producing Neutrons

Most reactors can produce the neutron flux required for the activation of calcium. However, the Georgia Tech reactor which is now under construction will not be available for use until late 1962 or early 1963.

Radioactive sources are also available which can produce neutron fluxes of the strength required. The most desirable source to use for this purpose is americium-beryllium, which has the advantage of a long half-life and lack of gamma activity. Shielding is only required for neutron emission. Other sources which could be used either require extensive shielding for gamma radiation, have low specific activity, or have short half-lives. Unfortunately, americium sources of the size required to produce the neutron flux required are not readily available.

C. Radiation Detection

To date, the use of crystals of thallium-activated sodium iodide [NaI(Tl)] coupled to cesium-antimony phototubes is unchallenged as the most efficient method for detecting gamma rays. The following characteristics of this type of detector have resulted in a widespread application of the scintillation counter as a radiation detector and gamma ray spectrometer: high density of the inorganic crystals, which is mainly responsible for the higher stopping power and greater sensitivity to gamma rays; high light output; suitable index of refraction; response proportional to the incident radiation; and fast decay time.

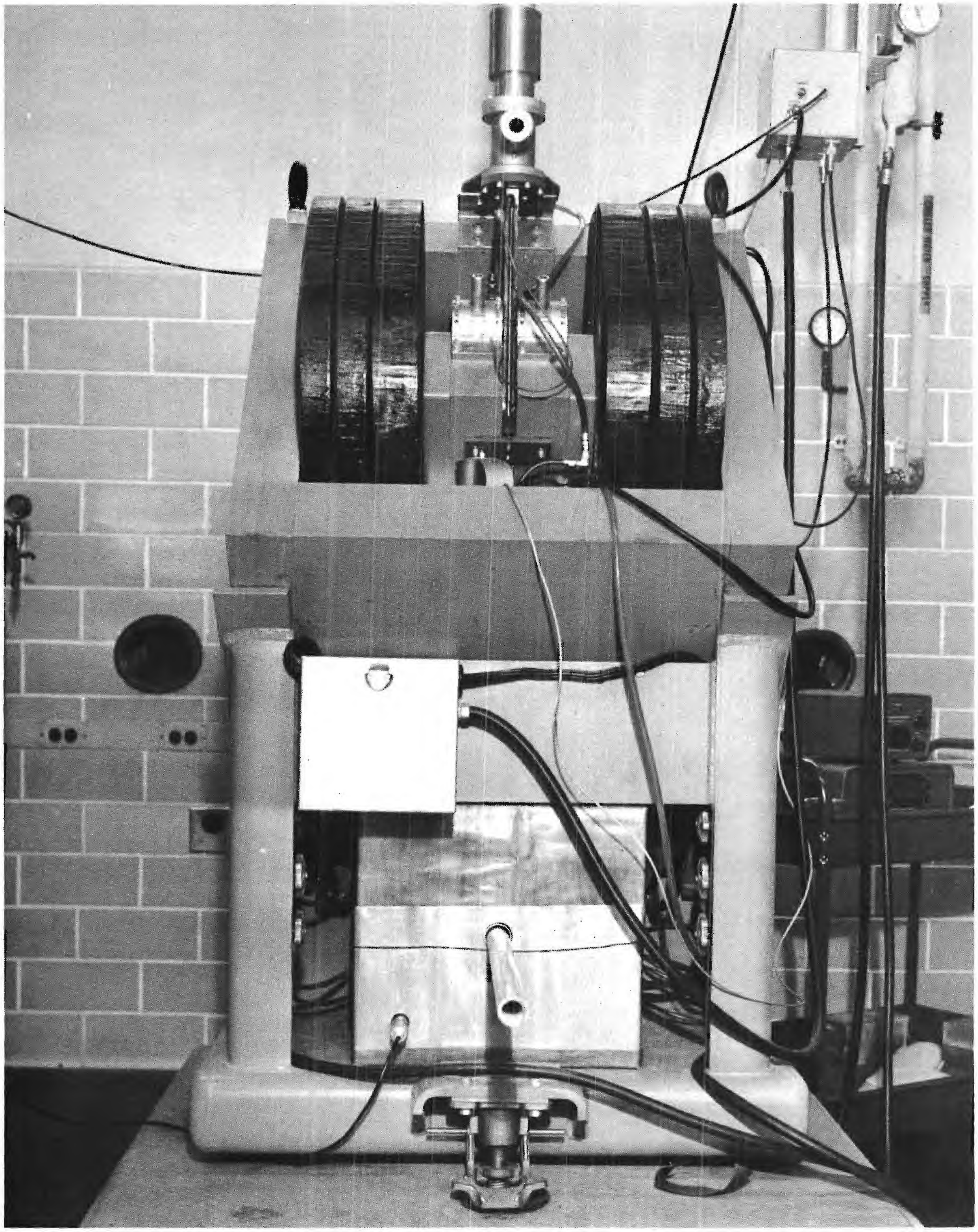

Figure 2. Neutron Irradiator in the Van de Graaff.

The basis of a scintillation counting system is the ability of the phosphor to convert into light emissions some fraction of the energy lost by ionization during the passage of a gamma ray through the material. This emitted light is picked up by the sensitive photocathode of a photomultiplier tube. The photocathode produces an electrical pulse which is similar to the light output from the crystal in both magnitude and duration. Because the electrical pulse coming from the phototube is of insufficient size to activate a scaler, additional amplification is supplied by an external amplifier.

For a given crystal size and energy of gamma ray the greatest total efficiency in counting is obtained from having the source situated in immediate contact with the crystal and on its central axis. In this experiment, not only is this proximity very nearly attained, but also two scintillation crystals are arranged with the sample situated between them, thereby approximating four-pi geometry. With the source situated in this manner, the emissions are isotropic, and thus a large number of interactions will occur laterally in the crystals.

Figure 3 is a view of the radiation-detection equipment located in the Radioisotopes Laboratory at Georgia Tech. On the right, the photo shows the two scintillation crystals with lead shields mounted vertically on a small tripod. The high voltage supply is at the top of the right center instrument bank and the external linear amplifier is at the bottom. The instrument in the left center of the photo is a 100-channel pulse height analyzer (Penco) manufactured by the Pacific Electro Nuclear Co. The Penco receives the electrical pulses from the external amplifier and stores them in channels according to their individual size. The memory of the Penco is recorded on tapes by a Victor printer shown at the right of the photo. Figure 4 is a block diagram of the pulse-counting equipment.

Equipment as expensive and elaborate as indicated in Figure 3 is not required for actual testing purposes. The equipment shown in Figure 3 was used to determine

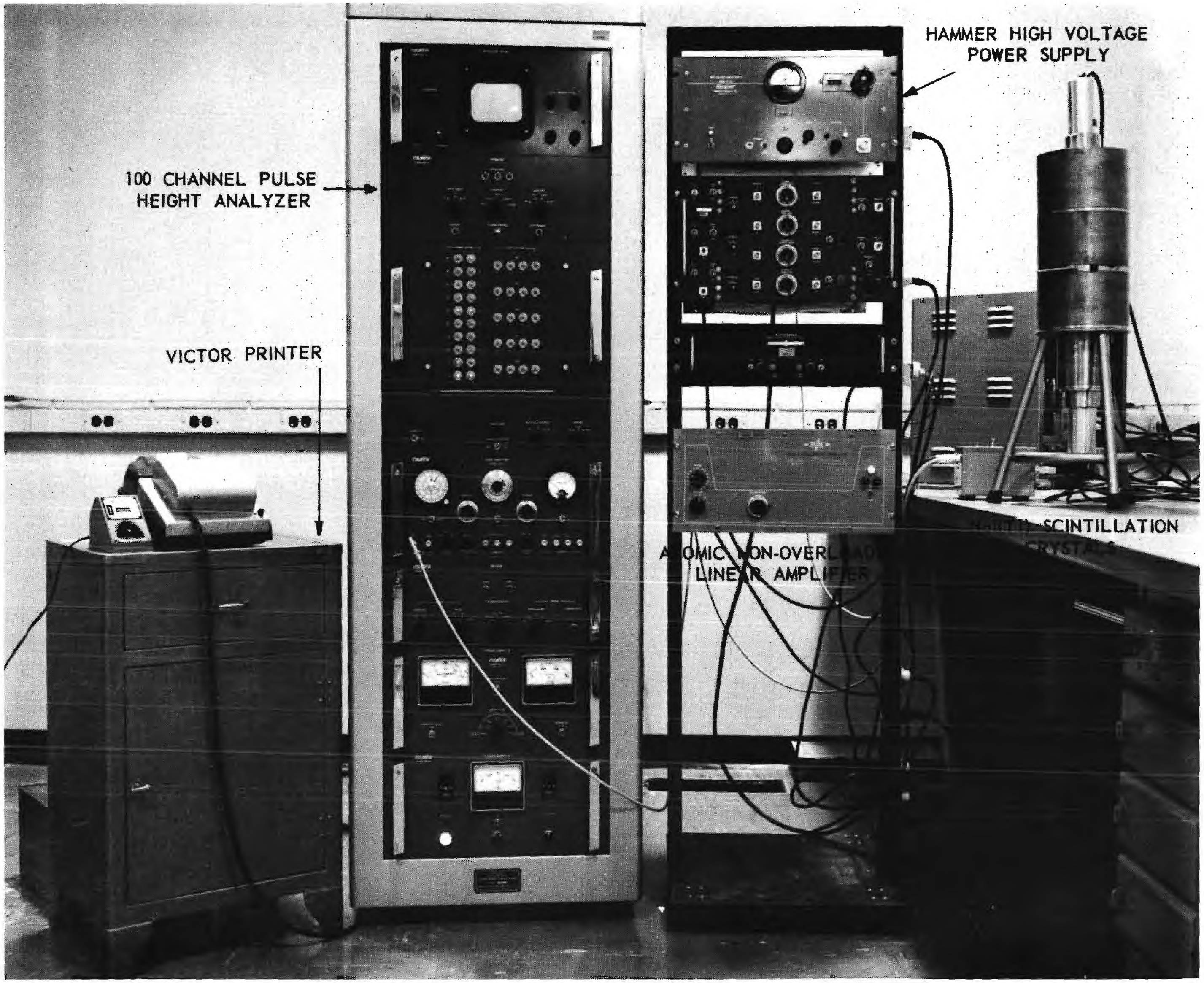

Figure 3. Radiation Detection Equipment.

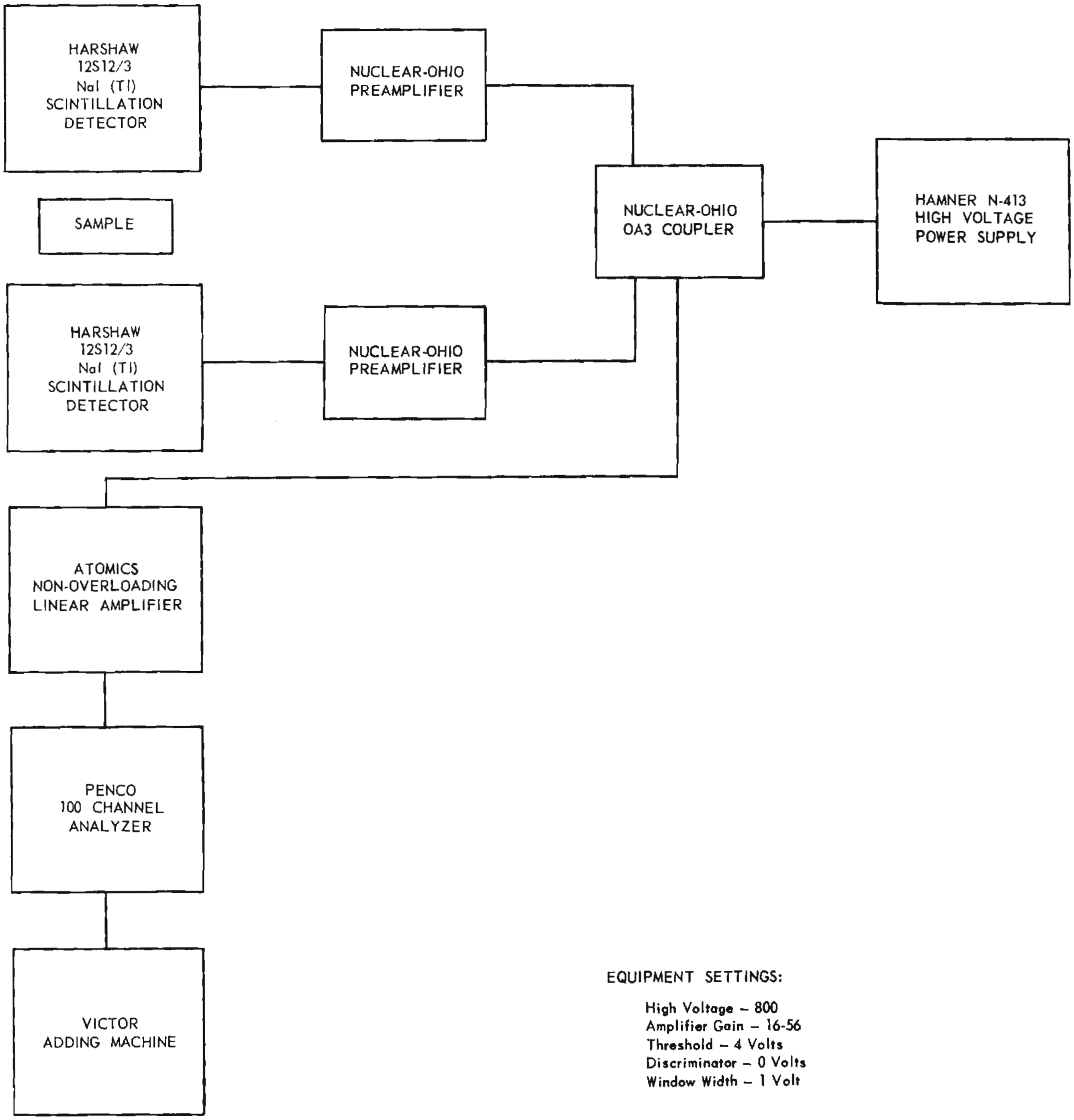

Figure 4. Schematic Diagram of Pulse Counter.

the best energy range for analysis and also to the minimum type of equipment which could be used for actual testing purposes.

The minimum equipment needed for measuring the activity of calcium-49 is as follows: (1) sodium iodide crystal, (2) linear amplifier, (3) discriminator, and (4) scaler. All of this equipment could be purchased for less than $3,000.

III. TESTING PROGRAM

A. General Background Information

If efficiency of mixing equipment is to be evaluated, a sampling and testing program must be designed to give the maximum amount of information from the collected data. In design of the experiment, Dr. Joseph Moder of the School of Industrial Engineering at Georgia Tech was consulted about the application of statistical concepts in the collection and the evaluation of these data.

A section of the highway on the interstate system was under construction in the Atlanta area and the two contractors consented to the sampling of their equipment. Each piece of equipment was a dual drum 34-E paver. Tests were also run on a laboratory mixer at the School of Civil Engineering.

Mixers located at two ready-mix plants were also sampled in the Atlanta area. One mixer was a tilting horizontal drum mixer with a capacity of approximately 3 cubic yards. The second mixer was a nontilting horizontal drum mixer of approximately 2 cubic yards capacity. Unfortunately this mixer was replaced with a new one before the entire sampling program was completed and the data for it are not complete.

The mixture selected for sampling at the ready-mix plants was a Class "A", vibrated, air-entrained concrete, as specified by the Georgia State Highway Department. The concrete sampled at the highway construction sites was classified as a Paving Class concrete. Mix proportions used at each of the highway projects and ready-mix plants sampled are given in Tables I, II, III, IV, and V.

TABLE I

PROPORTIONS USED IN A 1.385-CUBIC-YARD CONCRETE MIX,
PAVING CLASS CONCRETE, WRIGHT PAVING JOB,
INTERSTATE HIGHWAY PROJECT

Cement	716	Pounds
Fine aggregate	1519	Pounds
Coarse aggregate	1129	Pounds
	1694	Pounds
Water	43.12	Gallons
Air content	4	Per Cent by Volume

Note: Cement was obtained from the Signal Mountain Cement Co.; fine and coarse aggregate were obtained from Consolidated Quarries, Lithonia, Georgia.

TABLE II

PROPORTIONS USED IN A 1.385-CUBIC-YARD CONCRETE MIX,
PAVING CLASS CONCRETE, MACDOUGALD PAVING JOB,
INTERSTATE HIGHWAY PROJECT

Cement	716	Pounds
Fine aggregate	1287	Pounds
Coarse aggregate	1249	Pounds
	1873	Pounds
Water	41.21	Gallons
Air content	4	Per Cent by Volume

Note: Cement was obtained from the Marquette Cement Company; fine aggregate was obtained from Brown Bros., Butler, Georgia; and coarse aggregate was obtained from Tyrone Rock Products, Tyrone, Georgia.

TABLE III

PROPORTIONS USED IN A 3.5-CUBIC-YARD CONCRETE MIX,
CLASS "A", AIR-ENTRAINED CONCRETE,
MACDOUGALD WARREN, INCORPORATED

Cement	2135	Pounds
Fine aggregate	4256	Pounds
Coarse aggregate	6282	Pounds
Water	95	Gallons
Air-entraining agent	14	Ounces (produces 3 to 6 per cent air by volume)

Note: Cement was obtained from Universal Atlas Company; fine aggregate was obtained from Taylor Sand Co., Junction City, Georgia; and coarse aggregate was obtained from Tyrone Rock Products, Quarry No. 2, Mt. View, Georgia.

TABLE IV

PROPORTIONS USED IN A 4.3-CUBIC-FOOT CONCRETE MIX,
CLASS "A", AIR-ENTRAINED CONCRETE,
GEORGIA TECH MIXER

Cement	94	Pounds
Fine aggregate	166	Pounds
Coarse aggregate	318	Pounds
Water	5.48	Gallons
Air content	4	Per Cent by Volume

Note: Cement was obtained from the Penn Dixie Cement Company; fine aggregate was obtained from the Atlanta Sand Company, Gaillard, Georgia; and coarse aggregate was obtained from Stockbridge Stone Company, Norcross, Georgia.

TABLE V

PROPORTIONS USED IN A 2-CUBIC-YARD CONCRETE MIX,
CLASS "A", AIR-ENTRAINED CONCRETE,
CAMPBELL MATERIALS COMPANY

Cement	1174	Pounds
Fine aggregate	2246	Pounds
Coarse aggregate	3848	Pounds
Water	59	Gallons
Air content	4	Per Cent by Volume

Note: Cement was obtained from the Penn-Dixie Cement Company; fine aggregate was obtained from Atlanta Sand Company, Atlanta, Georgia; coarse aggregate was obtained from Consolidated Quarries, Lithonia, Georgia; and the air-entraining agent - Darex.

The first mixer sampled was a Rex 34-cubic-foot dual-drum highway paver owned by the Wright Contracting Company of Columbus, Georgia. The mixer was operated at a 10 per cent overload to give a mix of 1.385 cubic yards.

The second mixer sampled was of the same type but manufactured by the Koehring Company. It was owned by the MacDougald Construction Company of Atlanta, Georgia. Specifications and photographs of the two mixers may be seen in Appendix B (Figures B-1 and B-2).

Because of design, samples could not be withdrawn directly from the mixer but had to be collected as the concrete was discharged on to the roadbed.

The third mixer selected for sampling was a 3.5-cubic-yard horizontal tilting drum type manufactured by the T. L. Smith Corporation and owned by MacDougald Warren, Incorporated. The Hapeville Plant of MacDougald Warren, Incorporated, was selected because of their interest and cooperation, and because they possessed a standard type of stationary mixer used in the commercial production of ready-mixed concrete. In Appendix B (Figure B-3) is a picture of their plant and specifications of the mixer.

Again, because of design, it was impossible to withdraw samples directly from the different locations within the mixer. Therefore, after the pre-determined mixing time, the mixer was tilted, and during the 20 to 25 seconds necessary for discharge into a waiting truck, samples were drawn from the stream of concrete.

A laboratory mixer in the concrete laboratory at the Georgia Institute of Technology was next sampled. A picture of this Worthington 6.0-cubic-foot nontilting horizontal drum mixer and its specifications are shown in Appendix B (Figure B-4).

A partial experiment was run on a 2-cubic-yard Koehring nontilting horizontal drum at the Campbell Materials Company before its breakdown and replacement. Appendix B (Figure B-5) shows the plant of the Campbell Materials Company in Atlanta and gives the specifications for the mixer.

B. Design of the Experiment

The experiment was chosen to consist of five different mix times: 30, 45, 60, 120, and 180 seconds. Three samples were collected during the discharge of each batch and represented three different positions of the concrete in the mixer. The samples were evaluated for visual appearance of mixing adequacy, compressive strength, gradation of aggregate, and cement content. For the Hapeville and Georgia Tech mixers, the sampling and testing program was replicated three times to give a total of 45 samples for each mixer. The highway paving mixer experiments were replicated twice to give a total of 30 samples for each mixer, and the Campbell experiment was interrupted in the middle of the second replication.

The five mixing times used throughout the experiment were randomly selected and every effort was made to eliminate systematic errors. The materials used for any one mixer used during the tests were purchased from the same suppliers; the constituents of the batch were unchanged except for minor adjustment in water; the same person did the timing throughout the tests; the collection and processing of samples were as identical as possible; and the testing procedure was not altered.

C. Processing of Samples

Immediately after being drawn, the three samples were visually graded in one of three categories: well mixed, fair, and poor (see Appendix G for criteria for classification) and then processed for future testing. Two mortar samples to be used in determining the dispersion of cement by neutron activation were collected from each of the three samples. These small samples were secured by first taking 50 to 100 grams of the concrete mix, removing any large aggregate by passing the wet concrete through a number 4 sieve, and then filling 3/4-inch-diameter by 1/4-inch-height polystyrene containers with the concrete mortar. Figure 5 shows six of the mortar samples ready

Figure 5. Cement Mortar Samples Used for Evaluating Cement Content.

for the determination of cement content. Note the approximate size as compared to that of a nickel. Conventional 6-inch-diameter by 12-inch-height compressive strength cylinders were cast, and the remainder of each sample was used for a gradation test of the aggregate contained in the concrete. As indicated in Figure 6, the samples of fresh concrete used for the gradation test were washed over numbers 4, 50, and 200 sieves to remove the cement. To prevent initial setting prior to the washing, a retarding agent (Plastiment) was added to the samples to allow sufficient time to complete the washing process.

D. Testing of Samples

To relate mixing time to uniformity of a concrete mix, strength and gradation of aggregate were evaluated in addition to the dispersion of cement. Tests were first run for determining the uniformity of the aggregate gradation in each sample. After being washed, the aggregate was dried at 235° F for 24 hours and its fineness modulus determined by running a sieve analysis test.* Twenty eight-day ultimate compressive strength of the concrete was determined from the 6- by 12-inch cylinders under testing conditions prescribed by the American Society of Testing Materials (C85-54).

E. Determination of Cement Dispersion

In determining the dispersion of portland cement throughout a concrete mix by the use of radioisotopes, two methods are immediately available in designing the experiment.

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*Fineness modulus is a numerical coefficient used to describe the sieve analysis of an aggregate. The percentage of material coarser than each sieve size is calculated, and the sum of these percentages divided by 100 is the fineness modulus. The larger the aggregate, the higher is its fineness modulus.

Figure 6. Washing Technique for Removing Cement from Aggregate.

The first method utilizes the nuclear radiations emitted from a radioactive source which has been added to the mixer. The cement is tagged with an appropriate isotope, and after predetermined periods of mixing, samples from different parts of the batch are compared for radioactivity. Two objections or obstacles arise in using this method: first, the inability to tag uniformly the large quantity of cement used in most commercial size mixers; and second, the danger of radiation exposure to plant personnel due to the dust generated during mixing of the concrete and the danger to workmen while placing radioactive concrete. These objections prevented the application of radioisotopes to the mixer.

The second method consists of activation analysis. This procedure allowed the samples to be collected without the danger of radiation exposure and to be processed in a laboratory with proper shielding and suitable monitoring devices to eliminate any health hazard. In activation, the samples to be analyzed are placed in a high flux of slow neutrons produced by the Van de Graaff for a length of time sufficient to produce a measurable amount of radioisotope of the element to be determined. The activity present is a quantitative measurement of the element. Concrete mortar samples are collected from different parts of the batch, activated, and compared for radioactivity.

The problem consisted of finding an element within the portland cement that was not present in the other constituents of the concrete batch. Table VI lists the chemical properties of the typical cement and aggregate used.

By weight, calcium oxide comprises about 65 per cent of portland cement. For the material used in this experiment, calcium is only present in a very small percentage in the coarse aggregate, and is not found at all in the fine aggregate. Because only one per cent of the coarse aggregate

TABLE VI

CHEMICAL ANALYSIS OF PORTLAND CEMENT
AND FINE AND COARSE AGGREGATE*

Chemical Compound	Per Cent by Weight
Portland Cement	
Universal Atlas, Birmingham, Alabama	
CaO	65.66
SiO_2	22.24
Al_2O_3	5.96
Fe_2O_3	2.16
SO_3	1.88
MgO	0.93
Ins. Res.	0.40
K_2O	0.15
Na_2O	0.03
Fine Aggregate	
Alluvial Deposit Known as the Tuscaloosa Formation Taylor Sand Co., Junction City, Georgia	
SiO_2	98.00
Al_2O_3	1.20
H_2O	0.56
Org. Matter	0.18
Fe_2O_3	0.06
Coarse Aggregate	
Biotite Granite Gneiss Tyrone Rock Products Co., Quarry No. 2, Mt. View, Georgia	
SiO_2	74.70
Al_2O_3	13.92
Fe_2O_3	3.84
CaO_3	3.76
Na_2O	2.80
K_2O	0.76
MgO	0.20

*These values are typical of the proportions of chemical compounds found in other sources of aggregate and cement used in this research.

passes a number 4 sieve, only a minute fraction of the calcium present in a mortar sample would be contributed by the coarse aggregate. For this reason, radiation of calcium was selected as a means of measuring cement content.

An investigation of calcium was made to determine whether an isotope existed which, when subjected to neutron activation, would become traceable. It was also necessary to examine isotopes of the other chemical elements constituting concrete to insure that their energy of radiation and disintegration did not interfere with calcium measurements. The results of this investigation are shown in Table VII.

Although not in great abundance, ${}_{20}Ca^{48}$ was selected as the target which, after activation in the Van de Graaff, becomes the radioactive isotope ${}_{20}Ca^{49}$. This isotope was selected because of its relatively short half-like and traceable energy emissions during decay.

When bombarded by thermal neutrons, ${}_{20}Ca^{48}$ undergoes the following transformation:

$${}_{20}Ca^{48} + {}_{0}n^{1} \rightarrow {}_{20}Ca^{49}$$

${}_{20}Ca^{49}$ has been found to decay with a half-like of 8.9 ± 0.2 minute. The decay scheme, as determined by Martin, Cork, and Burson,[6] is shown in Figure 7.

The gamma ray spectrum of an activated cement mortar sample was studied to insure that the 3.07-mev (million-electron-volts) gamma ray emitted by Ca^{49} could be detected using the two 3-inch-diameter sodium chloride (thallium) crystals and the Penco 100-channel pulse height analyzer. The spectrum of an activated cement mortar sample as determined by the scintillation counting system is shown in Figure 8.

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[6] D. W. Martin, J. M. Cork, and S. B. Burson, "Decay of Ca^{49} and Sc^{49}," The Physical Review, Vol. 102, No. 2, April 15, 1956, pp. 457-458.

TABLE VII

ISOTOPES INHERENT IN ELEMENTS OF CONCRETE USED IN THE EXPERIMENT

Target Isotope	Abundance (%)	Radio-Nuclei	Type of Decay	Half-Life	Activation Cross-Section (BARNS)	Energy of Radiation and Disintegration (MEV)
$_1H^2$	0.015	$_1H^3$	β^-	12.26 Years	0.6	0.18
$_8O^{18}$	0.204	$_8O^{19}$	β^-	29.4 Seconds	0.21 mb	4.5 (30%) 2.9 (70%) 1.6 (70%)
$_{11}Na^{23}$	100.	$_{11}Na^{24}$	γ- β^-	14.97 Hours	0.6	4.122 (100%) 4.17 (.003%) 1.380; 2.758
$_{12}Mg^{26}$	11.29	$_{12}Mg^{27}$	γ- β^-	9.45 Minutes	50	1.75 (58%) 1.59 (42%) 0.834; 1.015
$_{13}Al^{27}$	100.	$_{13}Al^{28}$	γ- β^-	2.27 Minutes	0.21	2.87 (100%) 1.78
$_{14}Si^{30}$	3.05	$_{14}Si^{31}$	γ- β^-	2.62 Hours	0.12	1.49 1.264 (.07%)
$_{16}S^{34}$	4.215	$_{16}S^{35}$	γ- β^-	87 Days	0.26	0.167 (100%)
$_{16}S^{36}$	0.017	$_{16}S^{37}$	β^-	5.04 Minutes	0.14	1.6 (90%) 4.3 (10%) 3.09
$_{19}K^{39}$	93.08	$_{19}K^{40}$	γ- β^-	1.25×10^9 Years	3	1.33 (89%) 1.46 (11%)
$_{19}K^{40}$	0.012	K^{41}	Electron Capture			
$_{19}K^{41}$	6.91	$_{19}K^{42}$	β^-	12.52 Hours	1.0	2.04 (25%) 3.58 (75%) 1.51 (20%)
$_{20}Ca^{44}$	2.06	$_{20}Ca^{45}$	γ- β^-	164 Days	0.63	0.254
$_{20}Ca^{46}$	0.0033	$_{20}Ca^{47}$	β^- γ	4.7 Days		0.70 (76%) 1.94 (24%) 0.50 (5%) 0.81 (5%) 1.29 (71%)
$_{20}Ca^{48}$	0.185	$_{20}Ca^{49}$	β^- γ	8.9 Minutes	1.1	1.0, 2.12 3.07 (89%) 4.04 (10%) 4.7 (0.8%)
$_{26}Fe^{54}$	5.84	$_{26}Fe^{55}$	Electron Capture	2.60 Years	0.7	
$_{26}Fe^{58}$	0.31	$_{26}Fe^{59}$	β^- γ	45.1 Days	0.7	0.271 (46%) 0.462 (54%) 1.560 (.3%) 1.099 (57%) 1.289 (43%)

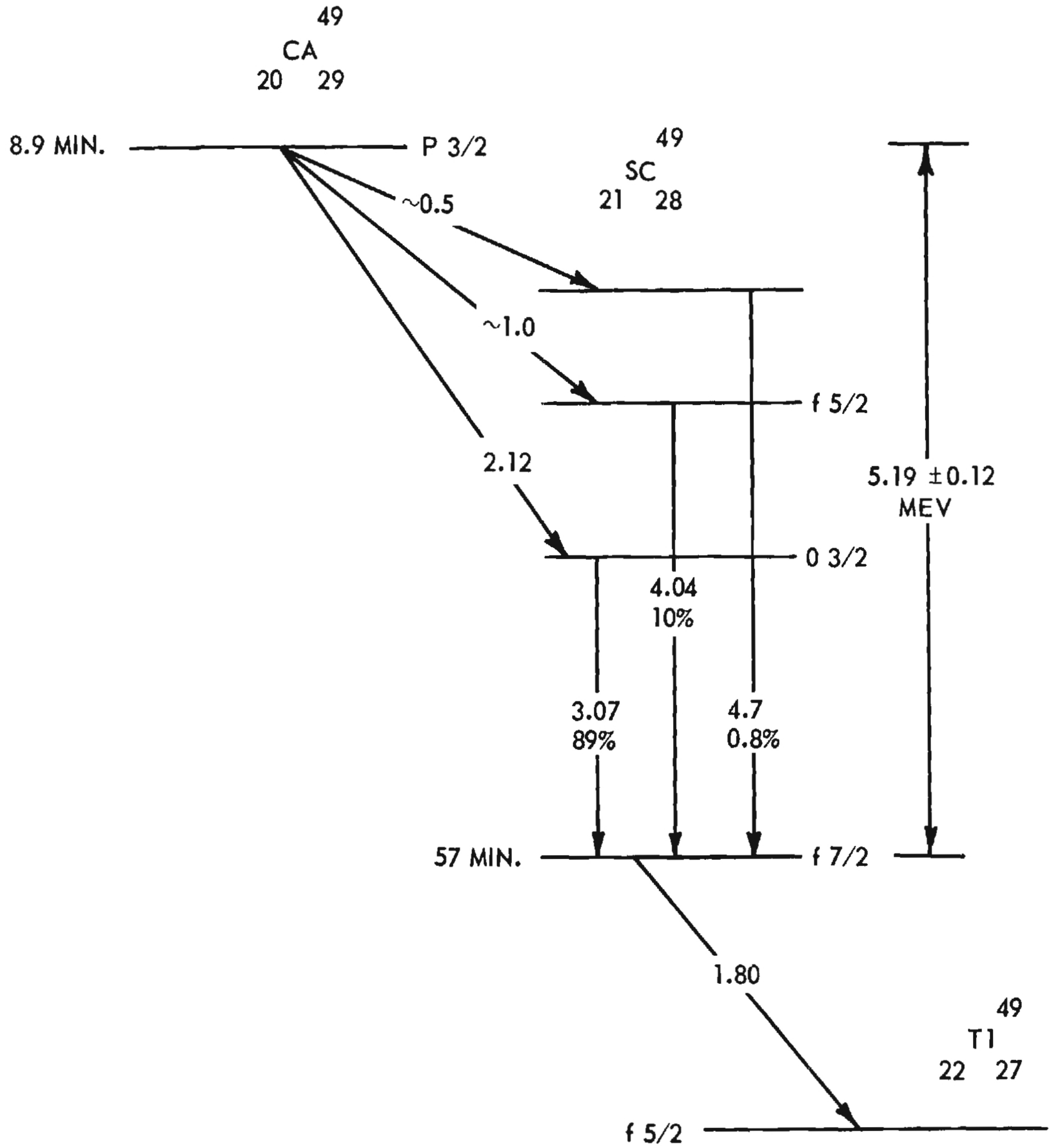

Figure 7. Decay Scheme of Calcium-49 and Scandium-49.

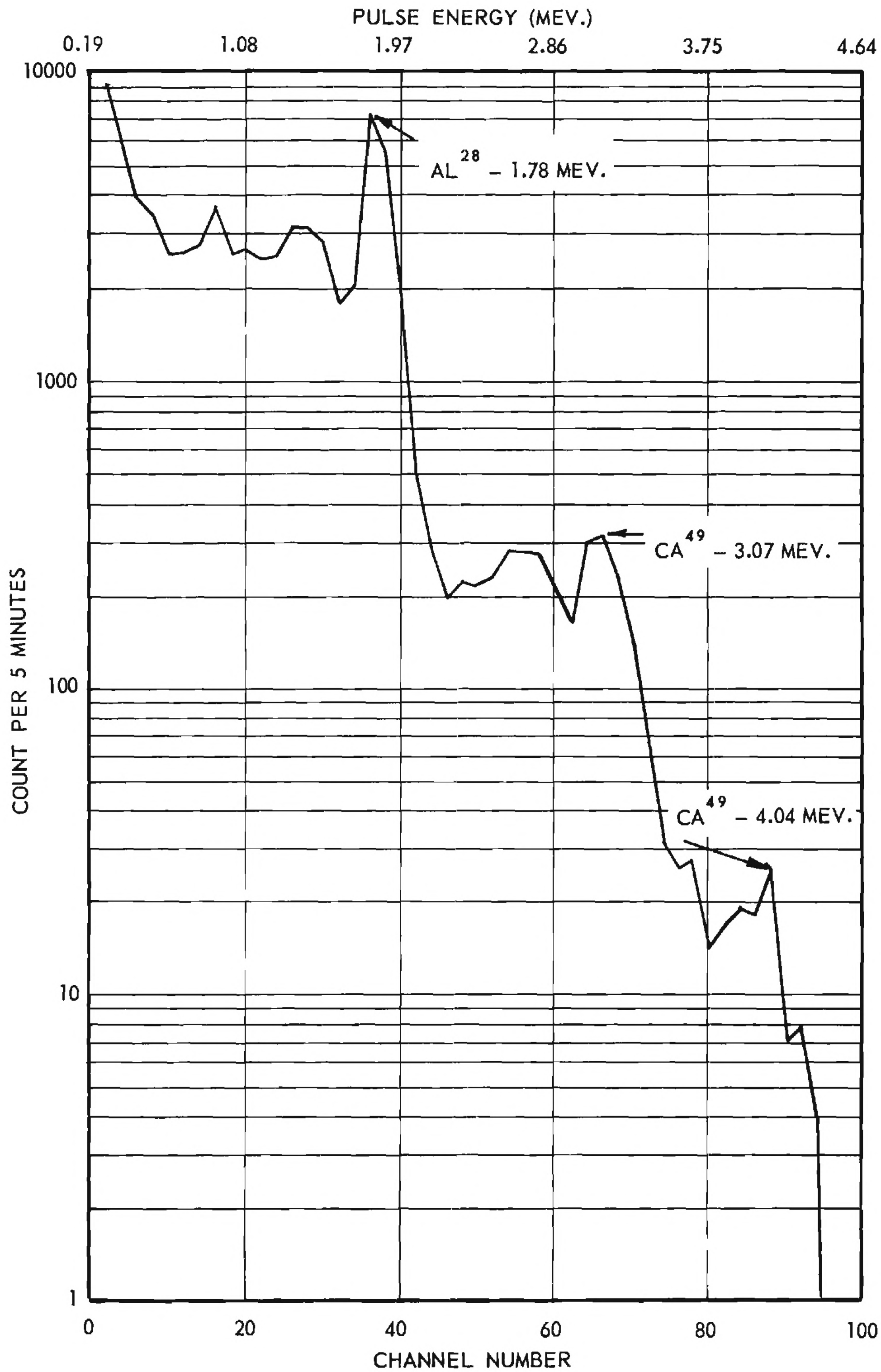

Figure 8. Gamma Ray Spectrum of Activated Mortar Sample.

A calibration of the scintillation spectrometer (100 channel analyzer, crystals, and amplifier) was necessary to determine in which channel the 3.07-mev peak would fall. Sources with known energy emissions were counted and plotted against channel number to give a calibration curve. The channel numbers corresponding to the different energy peaks are given in Table VIII. From the calibration curve shown in Figure 9, it was possible to select the approximate channel in which a 3.07-mev energy pulse would fall.

A decay study was then run on the 3.07-mev energy peak of an activated mortar sample as a check of its half-life. After activation, the sample was transferred to the scintillation counter and three 5-minute counts were recorded. The peak was found to cover channels 62 to 74. Table IX gives the total counts recorded under the 3.07-mev peak at the end of each counting period.

Figure 10 is a partial plot of the spectrum at the end of each 5-minute counting period; this plot graphically shows the decay of the 3.07-mev energy peak. Figure 11 shows the total counts recorded in channels 62 to 74 for the three 5-minute counts spaced 8 minutes apart. From Figure 11, the half-life of the peak was determined by reading the time on the abscissa corresponding to a 50-per-cent reduction in activity on the ordinate scale. A plot of the data determined the half-life of the peak to be 8.5 minutes. The difference of 0.4 minute between theoretical and observed decay time for ${}_{20}Ca^{49}$ was probably due to the presence of ${}_{16}S^{37}$ and ${}_{8}O^{19}$.

When irradiated, ${}_{16}S^{36}$ nuclei enter the excited state of ${}_{16}S^{37}$ and decay, emitting 3.09-mev gamma rays with a half-life of 5.04 minutes. Sulfur ionization therefore contributes to some of the activity recorded in the 3.07-mev peak of the spectrum, but this should in no way reduce

TABLE VIII

GAMMA SOURCES FOR ENERGY CALIBRATION
OF SCINTILLATION SPECTROMETER

Isotope	Energy Peaks (MEV)	Channel No.
Cs^{137}	0.667	11-1/2
Co^{60}	1.17	23
	1.33	26
	2.50	52-1/2
Po-Be	3.43	73
	3.94	84
	4.45	96

TABLE IX

DECAY STUDY OF 3.07-MEV ENERGY PEAK

Time After End of Irradiation (Minutes)	Count, Channels 62-74
1-6	2,409
9-14	1,242
17-22	648

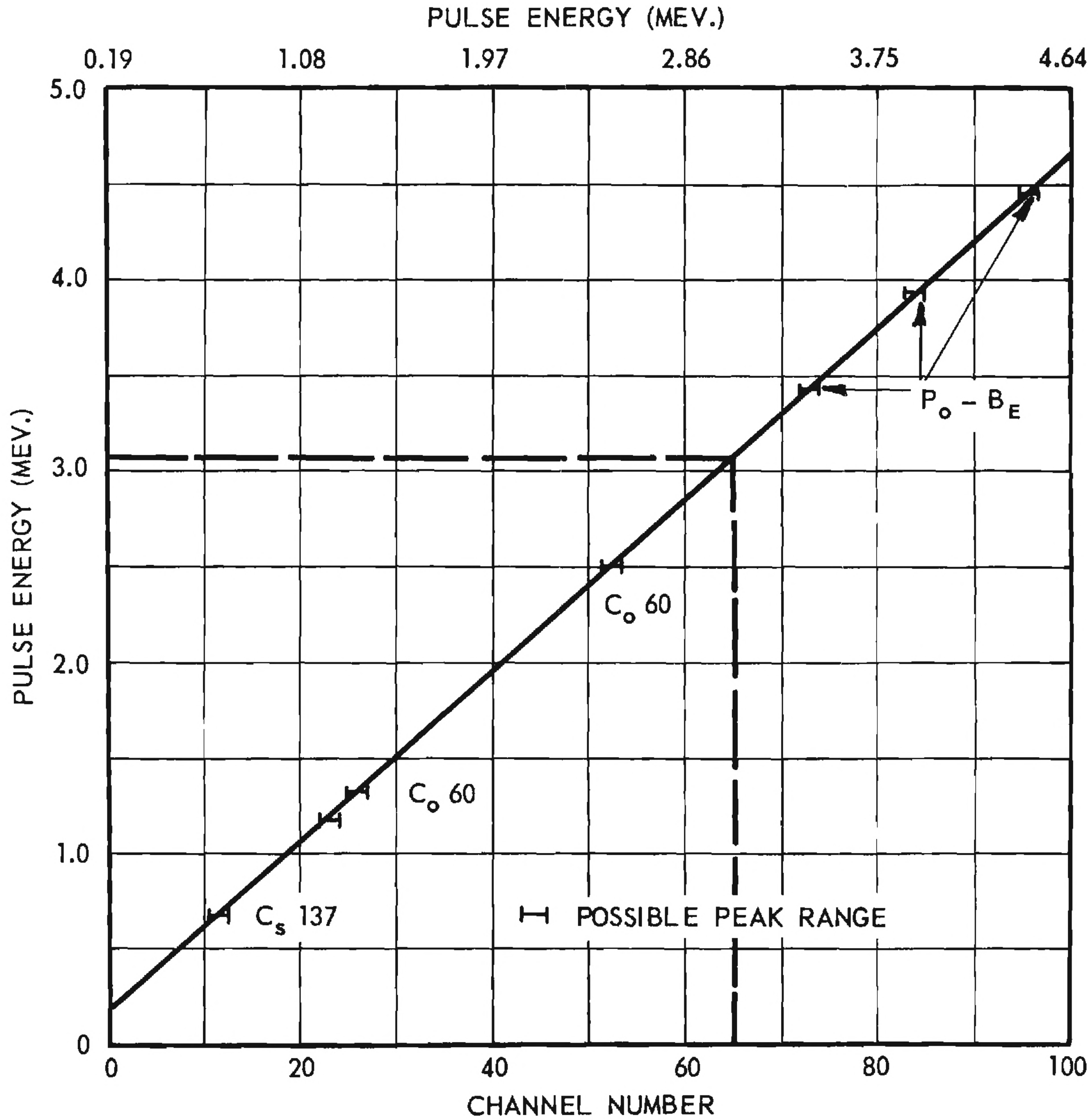

Figure 9. Calibration Curve for Scintillation Spectrometer.

Figure 10. Decay of 3.07-MEV Peak.

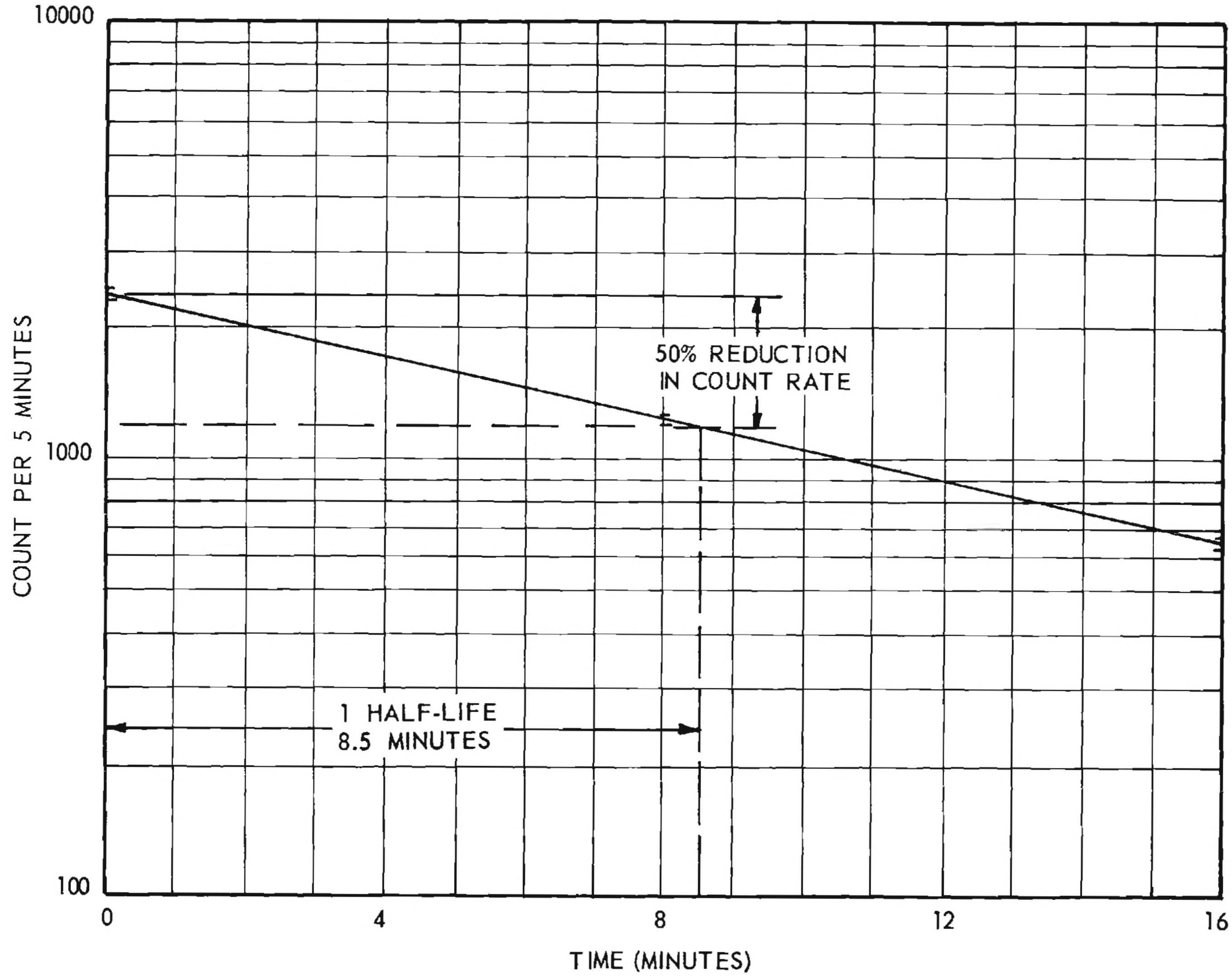

Figure 11. Half-Life Determination of 3.07-MEV Peak.

the accuracy in cement content determination because sulfur is only present in the cement in very small quantities. Because $_{8}O^{19}$ has a half-life of 29.4 seconds and counting does not start until 90 seconds time had elapsed after irradiation, the amount of activity caused by this isotope was considered to be negligible.

With the half-life of $_{20}Ca^{49}$ known to be approximately 8.9 minutes, it was decided that an irradiation period of 10 minutes for the collected mortar samples would give a sufficient number of counts to determine adequately the cement content. During this period the increase in activity is exponential with the time of irradiation.

The intensity of the 25-microampere beam varies during this 10-minute period among different samples and from day to day. Therefore, it was necessary to monitor the varying neutron flux with a small piece of indium foil which was irradiated along with each sample. The counts obtained from the indium foil were first normalized to correct for the varying foil weight and then further normalized to correct for the variation in neutron flux. The count of each mortar sample could then be normalized to the value that would have been recorded had the neutron flux been constant during the testing period. An example of the calculations necessary to normalize the count for each sample is given in Appendix E.

After a 10-minute exposure to the thermal neutron flux, the sample was removed from the irradiator and taken to the counting room. One minute was allowed for the transfer of the sample and an additional 30 seconds for transferring the monitoring indium foil, with each then being counted for 5 minutes.

The outputs from the two photomultiplier tubes were added electronically, giving a single composite spectrum which could be seen on the Penco pulse height analyzer scope. The spectrum was then printed on tape to give a permanent record of each sample's activity. The observed 5-minute count of the indium foil was recorded by a Geiger-Mueller counter.

To determine the cement content of mortar samples collected, a standard cement content versus count chart or graph was developed. Laboratory samples were made with known quantities of cement and were activated, counted, and plotted. Because of the random decay of radioactive isotopes, three observations were made of each standard sample and the best line through the points was determined by the method of least squares. The resulting cement content versus count rate curve is shown in Figure 12. It was from this line that point estimates of the cement of cast mortar samples were determined for mortar samples containing unknown amounts of cement.

IV. RESULTS

A. Analysis of Variance

Analysis of variance is probably the most powerful procedure in the field of experimental statistics. It allows the data collected to be rigorously analyzed and the conclusions to be accompanied by probability statements as to the correctness of inferences. To carry out the analysis, it is necessary to formulate a mathematical model in terms of the unknown parameters and the associated random variables. The quantitative physical characteristics (dependent variables) of interest in this study are the following:

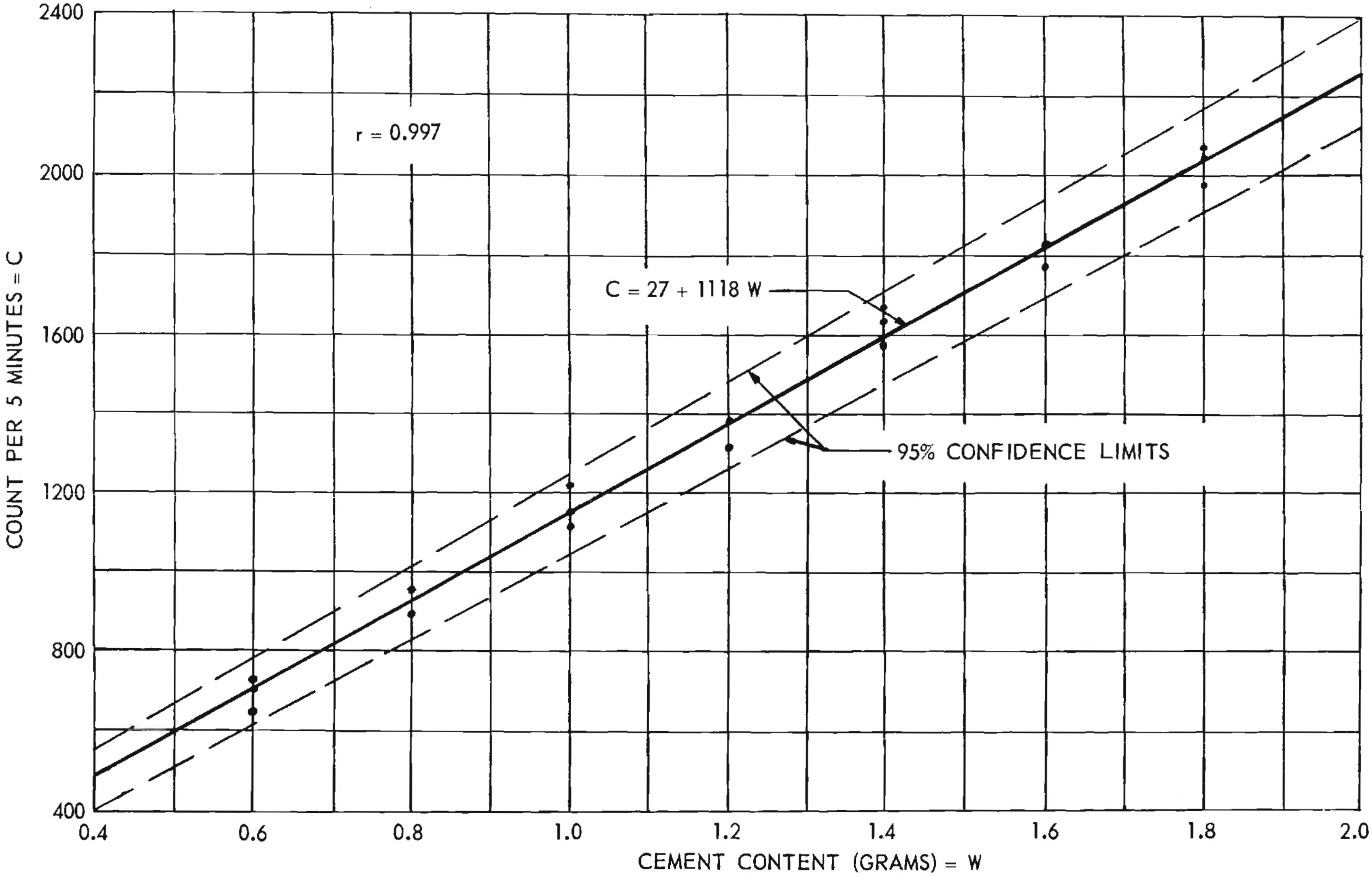

Figure 12. Cement Content Versus Count Chart.

(1) Aggregate fineness modulus

(2) Compressive strength

(3) Cement content of mortar

(4) Visual evaluation of mixing

Aggregate fineness modulus and cement content may appear to be independent variables since they are set by the particular mix samples. But in this investigation, the constituents enter the mixer in segregated slugs. This research is concerned with the determination of the dispersion of the constituents and therefore aggregate fineness modulus and cement content are dependent variables.

The independent variables of interest are as follows:

(1) Mixing time (T) 30, 45, 60, 120, and 180 seconds

(2) Position (P) of concrete in discharge stream or in mixer

(3) Replication (R) (experiment is run two or three times for each mixer).

The primary variables used in analysis of variance are shown in Table X. Analysis was made on the strength and fineness modulus characteristics, and on the average of the two cement content determinations for each sample. The mathematical model can be written as

$$y_{ijk} = \mu + T_i + R_j + RT_{ij} + P_k + PR_{jk} + PT_{ik} + PRT_{ijk}$$

In effects, this formula states that for an individual concrete sample, the strength, fineness modulus, or cement content (determination) for the _k_th position in the _j_th replication, mixed for _i_th seconds, will be an expected value μ, plus the sum of any main effects and interaction effects due to the three independent variables.

TABLE X

PRIMARY VARIABLES FOR ANALYSIS OF VARIANCE

Factor	Abbreviation	Subscript	No. Levels	Model
Mix time	T	i	5	Fixed
Replication	R	j	3 (2)*	Fixed
Discharge position	P	k	3	Fixed

*Wright and MacDougald paving jobs.

Table XI gives the design used for the analysis of variance. This design is known as a split-plot experiment. RT is used as an estimate of $\sigma^2_{\varepsilon 2}$, the main plot error, and PRT is taken as an estimate of $\sigma^2_{\varepsilon 1}$, the split-plot error.

B. Fineness Modulus

Tables A-I, A-III, A-V, A-VII, and A-IX give the values of aggregate fineness modulus of the samples collected during the experiment. Results of the analysis of variance are shown in Tables A-II, A-IV, A-VI, and A-VIII.

From Table A-IV for the MacDougald paving job it may be noted that the interaction term, PR, is significant at the 1 or 5 per cent level. The interaction terms are not significant in any of the other tables. The position is highly significant and replication is significant in Table A-VI. All other analyses of variance tables did not indicate any significant effect of mix time, replication or position of fineness modulus.

In Table A-VI by rejecting the hypothesis that the position of the concrete in the discharge stream does not affect the fineness modulus, it is possible to determine which positions differ. By the application of Tukey's procedure of contrasts,[7] one can conclude that the fineness modulus in Position 1 differs significantly from the fineness modulus in Positions 2 and 3, and that there is no significant difference between the fineness modulus in Positions 2 and 3.

C. Compressive Strength

Compressive strength is universally used as the index of concrete quality, but, used alone, it may be misleading. Samples drawn from two

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[7] Albert H. Bowker and Gerald J. Lieberman, "Analysis of Variance," Engineering Statistics, 1959, p. 295.

TABLE XI

SOURCE OF VARIATION, DEGREES OF FREEDOM, SUM OF SQUARES, AND EXPECTED MEAN SQUARES FOR SPLIT-PLOT EXPERIMENT

Source of Variation	Degrees of Freedom	Sum of Squares	Expected Mean Square
R	2 (1)	$\Sigma\, T^2_{.j.}/15 - T^2_{...}/45$ (30)*	$\sigma_{\varepsilon 2}^{2} + 15\theta_R^2$
T	4	$\Sigma\, T^2_{i..}/9^{(6)} - T^2_{...}/45$ (30)	$\sigma_{\varepsilon 2}^{2} + 9\theta_T^2$
RT	8 (4)	$\Sigma\Sigma\, T^2_{ij.}/3 - \Sigma\, T^2_{i..}/9^{(6)} - \Sigma\, T^2_{.j.}/15 + T^2_{...}/45$ (30)	$\sigma_{\varepsilon 2}^{2}$ (6)
P	2	$\Sigma\, T^2_{..k}/15^{(10)} - T^2_{...}/45$ (30)	$\sigma_{\varepsilon 1}^{2} + 15\theta_P^2$ (10)
PR	4 (2)	$\Sigma\Sigma\, T^2_{.jk}/15 - \Sigma\, T^2_{..k}/15 + T^2_{...}/45$ (3)	$\sigma_{\varepsilon 1}^{2} + 5\theta_{PR}^2$
PT	8	$\Sigma\Sigma\, T^2_{i.k}/3_{(2)} - \Sigma\, T^2_{i..}/9_{(6)} - \Sigma\, T^2_{..k}/15_{(10)} + T^2_{...}/45$ (30)	$\sigma_{\varepsilon 1}^{2} + 3\theta_{PT}^2$
PRT	16 (8)	$\Sigma\Sigma\Sigma\, y^2_{ijk} - \Sigma\Sigma\, T^2_{ij.}/3 - \Sigma\Sigma\, T^2_{i.k}/3 - \Sigma\Sigma\, T^2_{.jk}/5 -$ $T^2_{...}/45_{(30)} + \Sigma\, T^2_{i..}/9_{(6)} + \Sigma\, T^2_{.j.}/15 + \Sigma\, T^2_{..k}/15_{(10)}$	$\sigma_{\varepsilon 1}^{2}$
Total	44 (29)	$\Sigma\Sigma\Sigma\, y^2_{ijk} - T^2_{...}/45$ (30)	

*Figures in parentheses are for Wright and MacDougald paving jobs.

different batches of concrete may exhibit similar strength even though their uniformity of mixing is quite different. A sample with inadequate moisture content may be unacceptable from the standpoint of workability, yet may give high strength after being cast in a cylinder mold.

Tables A-X, A-XII, A-XIV, A-XVI, and A-XVIII show the ultimate compressive strengths obtained in breaking tests on the 6- by 12-inch concrete cylinders. The analysis of variance computed for compressive strengths of concrete are given in Tables A-XI, A-XIII, A-XV, and A-XVII.

The value of F obtained in testing the hypothesis that the different replications do not affect the strength in Table A-XV was 5.28. Even though this value exceeds $F_{0.05} = 4.46$, the authors believe this was a chance error, since no assignable reason for the error variance is evident.

In the past, numerous articles have been published correlating the strength of concrete with mixing time. Most of these articles indicate that one minute is the minimum length of time for suitable mixing of concrete, and that 2 minutes is highly desirable. However, the values of F computed in the analysis of variance for testing the mixing time effect in Tables A-XI, A-XIII, A-XV, and A-XVII indicated there was not a significant difference in strength for different mixing times. Position and replication also are not significant.

In a recent publication of research work performed by the Bureau of Public Roads on dual drum 34-E concrete mixers, optimum strength for a mixing time of 45 seconds was reported.[8] Furthermore this work indicated that a reduction in strength occurred with mixing longer than 45 seconds.

Immediately evident in Table A-XV is the highly significant value of F = 12.23 for testing the position hypothesis. It can be observed that from the data of

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[8]Woolf, Donald O., "Study of 34-E Dual-Drum Pavers," Public Roads, Journal of Highway Research, April 1960.

this experiment the strength of concrete varied significantly among each of the three positions in the discharge stream. Observing the F values computed in the various other tables, one must accept the hypothesis that there is no significant difference in strength because of interaction effect among the independent variables.

D. Cement Content

In the determination of cement content of a mortar sample, it was necessary to predict the cement content from a count rate subject to statistical variation. Therefore, it is necessary to indicate the reliability of any results reported.

Figure 12 shows the cement content versus count line and gives its equation and correlation coefficient, r. The value of r = 0.997 indicates a nearly perfect degree of association between the two related variables. The 95 per cent confidence limits are also shown in Figure 12.

Because there is an underlying physical relationship between observed count and cement content, it is appropriate to make point estimates of the cement content associated with a particular count. But because the observed count contains an error component, a confidence interval estimate is also needed to enable probability statements to be made about the true cement content of the samples.

For this experiment, a 95 per cent confidence interval was chosen around the regression line. For example, sample having a normalized count of 600 between channels 62 to 74 would have a point estimate equal to 0.513 gram of cement and a 95 per cent confidence interval equal to ±0.07 gram. The point estimate for a sample recording a normalized count of 1,800 per 5 minutes would equal 1.590 grams of cement and a 95 per cent confidence interval of ±0.11 gram around this cement content.

Point estimates of cement content on mortar samples were made using Figure 12. A ratio of grams of cement per gram of mortar was then computed for the samples and this information is contained in Tables A-XIX, A-XXI, A-XXIII, A-XXV, and A-XXVII. The analysis of variance for these data is given in Tables A-XX, A-XXII, A-XXIV, and A-XXVI.

For testing the hypothesis that the position of the concrete in the discharge stream has no effect on the cement content of a sample, the value of F was 14.69 in Table A-XXIV and 12.97 in Table A-XXVI. Since these values exceed both $F_{0.05}$ and $F_{0.01}$ values, one can conclude that there is a highly significant difference in cement content of mortar among samples located in different positions in the discharge stream or its corresponding position in the mixer. Replication effect is also significant in Table XXVI at the 5 per cent level.

Referring to the other values of F in the Tables A-XX and A-XXII, the main effects and interaction effects among the variables did not cause the cement content to differ significantly.

E. Visual Inspection

An objective type of evaluation was attempted to determine whether the authors could visually ascertain the degree of mixing by inspecting the samples of concrete discharged from the mixer. The samples used in the previously described tests were classified in one of three categories: well mixed, fair, and poor.

Compressive strength, fineness modulus, and cement content of samples were used to correlate visual classification to degree of mixing. Tables A-XXVIII through A-XLVII rank the samples according to their compressive strengths, fineness modulus, and cement content per gram of mortar. A visual estimate of the uniformity of mixing is given for each sample.

Although an analysis of variance cannot be performed on these data, it may be concluded from an observation of the data that the authors were unable to determine visually the degree of mixing uniformity. For example, in Table A-XXXVI, one of the samples having a fair rating fell within each third of the strength rank, and in Tables A-XXXVII, A-XXXVIII, and A-XXXIX there were batches classified as well mixed that had greater ranges of compressive strength, fineness modulus, and cement content per gram of mortar than were found in batches that were classified as being fair or poorly mixed.

V. SUMMARY OF RESULTS AND CONCLUSIONS

A. Summary of Results

The results obtained for fineness modulus, compressive strength, cement content, and visual evaluation of adequacy of mixing are as follows for the various mixers studied:

1. Fineness Modulus: For the dual drum 34-E mixer used on the MacDougald paving job, significant effect on fineness modulus for the position-replication interaction term was observed. For the MacDougald Warren mixer used at a ready-mix plant, replication of the experiment had significant effect on fineness modulus and position of the mix in the mixer had very significant effect on fineness modulus. All other main and interaction effects for all of the mixers studied were not significant.
2. Compressive Strength: For the MacDougald Warren, Incorporated, mixer, replication of the experiment had significant effect, and position of the mix in the mixer had very significant effect on compressive strength. All other main and interaction effects for the mixers studied were not significant.
3. Cement Content of the Mortar: For the MacDouglad Warren mixer, position of the mix in the mixer had very significant effect on cement content of the mortar. For the Georgia Tech mixer, replication of the experiment exhibited significant effect, and position of the mix in the mixer had very significant effect on cement content in the mortar. All other main and interaction terms for the mixers studied were not significant.
4. Visual Inspection of Concrete Mixing Adequacy: Using fineness modulus, compressive strength and cement content as criteria for adequacy of

mixing, it was not possible to determine the adequacy of mixing by visual observation for the mixers studied in this experiment.

B. Conclusions

The ease with which the sampling and testing program described in this report can be used in evaluating mixing efficiency justifies its application. Activation analysis appears to be a feasible method for determining the cement content of cast mortar samples. Although not equaling the accuracy obtained by chemical analysis, the cement content may be predicted to within approximately 10 per cent of its true value 95 per cent of the time for the mortar samples used in this experiment. These samples contained cement ranging from 0.4 to 1.8 grams in weight.

The principal advantages of activation analysis are the ease and speed of cement content determinations. The principal disadvantages are that a laboratory with trained personnel and equipped for irradiating samples and counting their disintegration emissions is required. However, these personnel need only have technical training in the operation of the equipment and the interpretation of the results, especially if simplier and less expensive equipment than that used in this research is used for radiation detection. If a neutron source is used for activation of the cement mortar samples, a person with only few hours training in radiation safety and counting can be used to make all observations. The experiment may not be performed on concretes containing aggregates of limestone, marble, or other stone with an appreciable calcium content.

It may be concluded from the data collected that some of the mixers sampled did not produce uniform concrete mixtures. It is of interest to note, however, that mixing time did not have significant effect on fineness modulus, compressive strength, or cement content of the mortar. Most mixing specifications for concrete require a maximum mixing time of one minute. In these experiments, the analyses of data for the 30-second mixer generally indicated no significant difference in quality of the mix obtained for longer mixing times.

Although no conclusions can be definitely drawn about other mixers, the results of this research may be an indication that some changes are needed in the blade angles, speed of rotation, capacity, etc. to insure the production of a uniform concrete mixture. However, mixing time did not have significant effect upon the uniformity of concrete for the mixing times studied in this experiment. These results indicate that mixers are probably producing a more uniform mix than is reflected in the usual construction specification in regard to mixing time.

Neutron activation may also be used to determine the dispersion of the fine aggregate portion of the concrete mix if the coarse and fine aggregate materials have different proportions of chemical elements in their make-up. Different sources of coarse and fine aggregates are frequently used by concrete producers to give a material of a specified gradation and to reduce aggregate costs than would be required using a single source for all sizes of aggregate required. The dispersion of the finer portions of the aggregate could be obtained in this mixture provided an element with measurable activity could be detected after activation.

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VII. APPENDIXES

APPENDIX A

TABLES OF RESULTS AND ANALYSIS OF VARIANCE

TABLE A-I

AGGREGATE FINENESS MODULUS, WRIGHT PAVING JOB

Replication	Position in Mixer or Discharge Stream	Mixing Time (Seconds) 30	45	60	120	180
1	1	6.32	5.83	5.81	5.42	5.84
	2	5.86	5.67	5.62	5.27	5.77
	3	5.80	5.58	5.82	5.37	5.64
2	1	5.88	5.95	5.94	5.61	5.89
	2	5.77	5.61	5.97	5.89	5.93
	3	5.76	5.84	4.85	5.75	5.99

TABLE A-II

ANALYSIS OF VARIANCE FOR FINENESS MODULUS, WRIGHT PAVING JOB

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F. Tests $F_{0.05}$	$F_{0.01}$
Replication	0.0340	1	0.0340	0.37	7.71	21.2
Mix time	0.4583	4	0.1146	1.25	6.39	16.0
RT	0.3655	4	0.0914			
Position	0.2189	2	0.1095	1.51	4.46	8.65
PR	0.0623	2	0.0312	0.43	4.46	8.65
PT	0.3177	8	0.0397	0.55	3.44	6.03
PRT	0.5805	8	0.0726			
Total	2.0372	29				

TABLE A-III

AGGREGATE FINENESS MODULUS, MACDOUGALD PAVING JOB

Replication	Position in Mixer or Discharge Stream	Mixing Time (Seconds) 30	45	60	120	180
1	1	6.11	5.96	5.76	5.95	5.94
	2	5.99	5.96	5.76	5.80	5.92
	3	5.84	5.80	5.85	5.75	5.68
2	1	5.79	5.97	5.98	5.89	5.69
	2	5.90	5.77	5.92	5.74	5.68
	3	6.10	6.35	6.34	5.91	5.78

TABLE A-IV

ANALYSIS OF VARIANCE FOR FINENESS MODULUS, MACDOUGALD PAVING JOB

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F. Tests $F_{0.05}$	$F_{0.01}$
Replication	0.0182	1	0.0182	0.45	7.71	21.2
Mix time	0.1586	4	0.0397	0.99	6.39	16.0
RT	0.1602	4	0.0401			
Position	0.0470	2	0.0235	3.13	4.46	8.65
PR	0.2588	2	0.1294	17.25**	4.46	8.65
PT	0.1066	8	0.0133	1.77	3.44	6.03
PRT	0.0597	8	0.0075			
Total	0.8091	29				

**Significant at the 1 and 5 per cent levels.

TABLE A-V

AGGREGATE FINENESS MODULUS, MACDOUGALD WARREN, INCORPORATED

Replication	Position in Mixer or Discharge Stream	Mixing Time (Seconds) 30	45	60	120	180
1	1	4.61	4.78	4.72	5.03	5.09
	2	5.09	5.05	5.09	5.01	4.96
	3	5.22	4.98	5.09	5.17	5.09
2	1	4.76	4.49	4.76	4.99	4.31
	2	5.01	4.85	5.05	5.07	5.17
	3	5.07	4.96	4.78	4.96	5.30
3	1	4.73	4.69	4.68	4.32	4.96
	2	5.00	4.91	4.94	5.15	5.08
	3	5.16	4.81	5.00	5.27	4.97

TABLE A-VI

ANALYSIS OF VARIANCE FOR FINENESS MODULUS,
MACDOUGALD WARREN, INCORPORATED

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F. Tests $F_{0.05}$	$F_{0.01}$
Replication	0.0853	2	0.0427	7.91*	4.46	8.65
Mix time	0.1689	4	0.0422	7.81	3.84	7.01
RT	0.0428	8	0.0054			
Position	0.9913	2	0.4957	9.80**	3.63	6.23
PR	0.0455	4	0.0114	0.23	3.01	4.77
PT	0.0509	8	0.0064	0.13	2.59	3.89
PRT	0.8090	16	0.0506			
Total	2.1939	44				

*Significant at the 5 per cent level.

**Significant at the 1 and 5 per cent levels (very significant).

TABLE A-VII

AGGREGATE FINENESS MODULUS, GEORGIA TECH MIXER

Replication	Position in Mixer or Discharge Stream	Mixing Time (Seconds) 30	45	60	120	180
1	1	5.26	5.32	5.33	5.12	5.40
	2	5.39	5.34	5.23	5.25	5.43
	3	5.55	5.16	5.08	5.77	5.11
2	1	5.66	5.55	5.33	5.25	5.35
	2	5.78	5.82	5.30	5.32	5.35
	3	5.57	6.14	5.19	5.26	5.60
3	1	5.74	5.41	5.46	5.56	5.38
	2	5.45	5.38	5.41	5.58	5.39
	3	5.44	5.37	5.50	5.47	5.33

TABLE A-VIII

ANALYSIS OF VARIANCE FOR FINENESS MODULUS, GEORGIA TECH MIXER

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F. Tests $F_{0.05}$	$F_{0.01}$
Replication	0.2745	2	0.1373	1.87	4.46	8.65
Mix time	0.3064	4	0.0766	1.04	3.84	7.01
RT	0.5886	8	0.0736			
Position	0.0063	2	0.0032	0.09	3.63	6.23
PR	0.0621	4	0.0155	0.45	3.01	4.77
PT	0.1001	8	0.0125	0.37	2.59	3.89
PRT	0.5479	16	0.0342			
Total	1.8859	44				

TABLE A-IX

AGGREGATE FINENESS MODULUS,* CAMPBELL MATERIALS COMPANY

Replication	Position in Mixer or Discharge Stream	Mixing Time (Seconds) 45	60	120	180
1	1	5.33	5.56	5.51	5.23
	2	5.33	5.64	5.52	5.18
	3	5.64	5.71	5.50	5.25
2	1	5.10		5.29	
	2	5.21		5.28	
	3	5.33		5.28	

*Incomplete experiment.

TABLE A-X

28-DAY COMPRESSIVE STRENGTHS IN POUNDS PER SQUARE INCH
FOR WRIGHT PAVING JOB

Replication	Position in Mixer or Discharge Stream	Mixing Time (Seconds) 30	45	60	120	180
1	1	3360	3900	2460	4520	3290
	2	3310	3530	2460	5010	3290
	3	2420	3690	3290	4270	3400
2	1	3100	2840	2870	2830	2910
	2	3240	2790	3160	2740	3000
	3	2840	2960	3010	2240	3080

TABLE A-XI

ANALYSIS OF VARIANCE FOR COMPRESSIVE STRENGTHS
FOR WRIGHT PAVING JOB

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F. Tests $F_{0.05}$	$F_{0.01}$
Replication	24,596.033	1	24,596.033	2.0216	7.71	21.2
Mixing time	17,968.797	4	4,492.199	.3692	6.39	16.0
RT	48,667.467	4	12,166.866			
Position	915.267	2	457.6335	.6328	4.46	8.65
PR	56.867	2	28.4335	.0393	4.46	8.65
PT	11,449.403	8	1,431.175	1.9791	3.44	6.03
PRT	5,785.133	8	723.142			
Total	109,438.967	29				

TABLE A-XII

28-DAY COMPRESSIVE STRENGTHS IN POUNDS PER SQUARE INCH
FOR MACDOUGALD PAVING JOB

Replication	Position in Mixer or Discharge Stream	Mixing Time (Seconds) 30	45	60	120	180
1	1	4030	5390	4120	2780	3340
	2	5170	5450	4260	1900	3580
	3	3330	5550	4140	3140	3530
2	1	3000	4040	4650	4420	4760
	2	2730	4200	4530	4870	4630
	3	3050	3940	3980	4640	4430

TABLE A-XIII

ANALYSIS OF VARIANCE FOR COMPRESSIVE STRENGTHS FOR MACDOUGALD PAVING JOB

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F. Tests $F_{0.05}$	F. Tests $F_{0.01}$
Replication	1,555.203	1	1,555.203	0.0467	7.71	21.2
Mixing time	59,299.2	4	14,824.8	0.4450	6.39	16.0
RT	133,253.47	4	33,313.37			
Position	1,264.07	2	632.04	.2467	4.46	8.65
PR	391.4	2	195.7	.0764	4.46	8.65
PT	8,860.6	8	1,107.57	0.4324	3.44	6.03
PRT	20,493.93	8	2,561.7			
Total	225,117.87	29				

TABLE A-XIV

28-DAY COMPRESSIVE STRENGTHS IN POUNDS PER SQUARE INCH OF CLASS "A" CONCRETE FOR MACDOUGALD WARREN, INCORPORATED

Replication	Position in Mixer or Discharge Stream	Mixing Time (Seconds) 30	45	60	120	180
1	1	5850	5210	6230	5180	4730
	2	4210	4980	5210	4720	3980
	3	2650	4360	3880	3890	4330
2	1	5420	5050	5040	3830	3570
	2	5110	5370	4880	3300	2810
	3	3230	4220	3760	3600	3000
3	1	5390	6170	3220	3750	3270
	2	4380	4650	3040	3290	3390
	3	2190	3250	3220	2560	3000

TABLE A-XV

ANALYSIS OF VARIANCE FOR COMPRESSIVE STRENGTHS
FOR MACDOUGALD WARREN, INCORPORATED

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F. Tests $F_{0.05}$	F. Tests $F_{0.01}$
Replication	71,448	2	35,724	5.28*	4.46	8.65
Mix time	83,942	4	20,986	3.10	3.84	7.01
RT	54,106	8	6,763			
Position	145,230	2	72,615	12.23**	3.63	6.23
PR	6,061	4	1,515	0.25	3.01	4.77
PT	57,222	8	7,153	1.20	2.59	3.89
PRT	94,969	16	5,936			
Total	512,978	44				

* Significant at the 5 per cent level.

** Significant at the 1 and 5 per cent levels (very significant).

TABLE A-XVI

28-DAY COMPRESSIVE STRENGTHS IN POUNDS PER SQUARE INCH OF
CLASS "A" CONCRETE FOR GEORGIA TECH MIXER

Replication	Position in Mixer or Discharge Stream	Mixing Time (Seconds) 30	45	60	120	180
1	1	3630	2820	3420	3410	3870
	2	3240	2730	2910	2770	3560
	3	3430	2820	3000	2820	3330
2	1	2810	3230	3310	2580	3470
	2	2870	3400	2860	2730	3270
	3	3760	2060	3220	2640	3470
3	1	3110	3750	2800	3270	3310
	2	2740	3530	2060	3360	3090
	3	3450	3520	3280	2090	3170

TABLE A-XVII

ANALYSIS OF VARIANCE FOR COMPRESSIVE STRENGTH FOR GEORGIA TECH MIXER

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F. Tests $F_{0.05}$	F. Tests $F_{0.01}$
Replication	1,458.179	2	729.0895	.2951	4.46	8.65
Mix time	15,867.912	4	3,966.978	1.6055	3.84	7.01
RT	19,767.154	8	2,470.894			
Position	4,845.645	2	2,422.823	1.8696	3.63	6.23
PR	1,951.288	4	487.822	.3764	3.01	4.77
PT	17,295.688	8	2,161.961	1.6683	2.59	3.89
PRT	20,734.046	16	1,295.878			
Total	81,919.912	44				

TABLE A-XVIII

28-DAY COMPRESSIVE STRENGTHS IN POUNDS PER SQUARE INCH OF CLASS "A" CONCRETE* FOR CAMPBELL MATERIALS COMPANY

Replication	Position in Mixer or Discharge Stream	Mixing Time (Seconds) 45	60	120	180
1	1	6540	5830	4130	4010
	2	4840	4210	3820	4280
	3	4850	4030	3730	4250
2	1	6640		4890	
	2	5920		5160	
	3	4620		4590	

*Incomplete experiment.

TABLE A-XIX

CEMENT CONTENT OF MORTAR SAMPLES IN GRAMS CEMENT PER GRAMS MORTAR FROM WRIGHT PAVING JOB

Replication	Position in Mixer or Discharge Stream	Mixing Time (Seconds) 30	45	60	120	180
1	1	.33	.38	.37	.39	.38
		.32	.43	.38	.41	.32
	2	.38	.35	.32	.34	.36
		.39	.42	.32	.41	.42
	3	.30	.37	.33	.37	.41
		.34	.37	.38	.41	.40
2	1	.40	.38	.36	.40	.36
		.41	.38	.41	.35	.37
	2	.35	.39	.38	.38	.41
		.39	.41	.34	.41	.38
	3	.39	.40	.40	.39	.40
		.38	.38	.35	.37	.40

TABLE A-XX

ANALYSIS OF VARIANCE FOR CEMENT CONTENT OF MORTAR SAMPLES FROM WRIGHT PAVING JOB

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F. Tests $F_{0.05}$	$F_{0.01}$
Replication	0.0014	1	0.0014	2.33	7.71	21.2
Mix time	0.0042	4	0.00105	1.75	6.39	16.0
RT	0.0024	4	0.0006			
Position	0.0000	2	0.0000	0.00	4.46	8.65
PR	0.0001	2	0.00005	0.11	4.46	8.65
PT	0.0043	8	0.0005375	1.23	3.44	6.03
PRT	0.0035	8	0.0004375			
Total	0.0159	29				

TABLE A-XXI

CEMENT CONTENT OF MORTAR SAMPLES IN GRAMS CEMENT PER GRAMS MORTAR FROM MACDOUGALD PAVING JOB

Replication	Position in Mixer or Discharge Stream	Mixing Time (Seconds) 30	45	60	120	180
1	1	.16	.18	.18	.22	.17
		.16	.16	.24	.19	.20
	2	.19	.14	.19	.20	.20
		.21	.19	.20	.23	.19
	3	.21	.18	.18	.22	.20
		.19	.14	.23	.23	.19
2	1	.21	.14	.18	.18	.19
		.22	.10	.17	.21	.18
	2	.20	.17	.15	.20	.17
		.19	.18	.17	.21	.20
	3	.22	.18	.17	.21	.21
		.17	.19	.19	.18	.17

TABLE A-XXII

ANALYSIS OF VARIANCE FOR CEMENT CONTENT OF MORTAR SAMPLES FROM MACDOUGALD PAVING JOB

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F. Tests $F_{0.05}$	$F_{0.01}$
Replication	0.00066	1	0.00066	1.97	7.71	21.2
Mix time	0.00586	4	0.00142	4.24	6.39	16.0
RT	0.00134	4	0.000335			
Position	0.00061	2	0.000305	0.84	4.46	8.65
PR	0.00000	2	0.00000	0.00	4.46	8.65
PT	0.00076	8	0.000095	0.26	3.44	6.03
PRT	0.00290	8	0.0003625			
Total	0.01195	29				

TABLE A-XXIII

CEMENT CONTENT OF MORTAR SAMPLES IN GRAMS CEMENT PER GRAMS MORTAR
FROM MACDOUGALD WARREN, INCORPORATED

Replication	Position in Mixer or Discharge Stream	Mixing Time (Seconds) 30	45	60	120	180
1	1	.22	.20	.32	.27	.32
		.22	.22	.36	.33	.30
	2	.12	.28	.20	.26	.23
		.22	.21	.23	.29	.29
	3	.16	.20	.18	.25	.20
		.18	.21	.26	.18	.28
2	1	.35	.33	.25	.21	.21
		.33	.33	.23	.24	.28
	2	.27	.21	.25	.21	.21
		.32	.30	.29	.25	.25
	3	.24	.19	.19	.18	.14
		.32	.31	.21	.23	.21
3	1	.35	.43	.29	.32	.27
		.34	.36	.32	.32	.13
	2	.18	.16	.20	.23	.15
		.25	.19	.24	.20	.20
	3	.20	.21	.22	.23	.22
		.20	.24	.28	.18	.23

TABLE A-XXIV

ANALYSIS OF VARIANCE FOR CEMENT CONTENT OF MORTAR SAMPLES
FROM MACDOUGALD WARREN, INCORPORATED

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F Tests $F_{0.05}$	F Tests $F_{0.01}$
Replication	0.0013	2	.000650	0.14	4.46	8.65
Mix time	0.0033	4	.000825	0.18	3.84	7.01
RT	0.0367	8	.004587			
Position	0.0435	2	.02175	14.69**	3.63	6.23
PR	0.0128	4	.0032	2.16	3.01	4.77
PT	0.0049	8	.000612	0.41	2.59	3.89
PRT	0.0237	16	.001481			
Total	0.1262	44				

**Significant at the 1 and 5 per cent levels (very significant).

TABLE A-XXV

CEMENT CONTENT OF MORTAR SAMPLES IN GRAMS CEMENT PER GRAMS MORTAR
FROM GEORGIA TECH MIXER

Replication	Position in Mixer or Discharge Stream	Mixing Time (Seconds) 30	45	60	120	180
1	1	.21	.22	.19	.23	.23
		.19	.21	.26	.21	.21
	2	.18	.25	.22	.19	.19
		.22	.23	.23	.20	.20
	3	.21	.18	.16	.24	.22
		.22	.23	.19	.23	.22
2	1	.19	.16	.17	.18	.19
		.18	.20	.19	.21	.21
	2	.16	.20	.17	.20	.20
		.18	.17	.17	.19	.17
	3	.20	.18	.16	.18	.20
		.17	.18	.18	.18	.20
3	1	.20	.19	.20	.21	.22
		.23	.21	.16	.20	.19
	2	.23	.20	.17	.19	.22
		.18	.19	.17	.21	.15
	3	.20	.19	.18	.19	.17
		.18	.21	.21	.19	.22

TABLE A-XXVI

ANALYSIS OF VARIANCE FOR CEMENT CONTENT OF MORTAR SAMPLES FROM GEORGIA TECH MIXER

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	F. Tests $F_{0.05}$	F. Tests $F_{0.01}$
Replication	.00569	2	.002845	7.7701*	7.71	21.2
Mix time	.00109	4	.0002725	2.5057	6.39	16.0
RT	.00087	8	.00010875			
Position	.00245	2	.001225	12.97**	4.46	8.65
PR	.00007	4	.0000775	.18538	4.46	8.65
PT	.00124	8	.000155	1.6419	3.44	6.03
PRT	.00151	16	.0000944			
Total	.01292					

* Significant at the 5 per cent level.

**Significant at the 1 and 5 per cent levels (very significant).

TABLE A-XXVII

CEMENT CONTENT OF MORTAR SAMPLES IN GRAMS CEMENT PER GRAMS MORTAR FROM CAMPBELL MATERIALS COMPANY*

Replication	Position in Mixer or Discharge Stream	Mixing Time (Seconds) 45	60	120	180
1	1	.27	.32	.25	.30
		.32	.31	.29	.24
	2	.21	.27	.28	.28
		.17	.27	.33	.27
	3		.29	.23	.24
		.23	.21	.29	.25
2	1	.31		.26	
		.31		.27	
	2	.24		.26	
		.34		.26	
	3	.25		.26	
		.32		.28	

*Incomplete experiment.

TABLE A-XVIII

COMPRESSIVE STRENGTHS AND VISUAL CLASSIFICATION
OF CONCRETE SAMPLES, WRIGHT PAVING JOB

Mix Time (Seconds)	Sample Number Replication	Sample Number Position	Compressive Strength (Lb/Sq In)	Degree of Mixing*
120	1	2	5010	A
120	1	1	4520	A
120	1	3	4270	A
45	1	2	3900	A
45	1	3	3690	A
45	1	2	3530	A
180	1	3	3400	A
30	1	1	3360	A
30	1	2	3310	A
180	1	1	3290	A
180	1	2	3290	A
60	1	3	3290	A
30	2	2	3240	A
60	2	2	3160	A
30	2	1	3100	A
180	2	3	3080	A
60	2	3	3010	A
180	2	2	3000	A
45	2	3	2960	A
180	2	1	2910	A
60	2	1	2870	A
45	2	1	2840	A
30	2	3	2840	A
120	2	1	2830	A
45	2	2	2790	A
120	2	2	2740	A
60	1	1	2460	A
60	1	2	2460	A
30	1	3	2420	A
120	2	3	2240	A

*A - Well mixed
B - Fair
C - Poor

TABLE A-XXIX

RANGE OF COMPRESSIVE STRENGTHS IN CONCRETE BATCH, WRIGHT PAVING JOB

Mix Time (Seconds)	Replication	Range of Compressive Strength Among Positions (Lb/Sq In)	Visual Classification of Uniformity*
30	1	940	A
60	1	830	A
120	1	740	A
120	2	590	A
30	2	400	A
45	1	370	A
60	2	290	A
45	2	170	A
180	2	170	A
180	1	110	A

*A - Well mixed
B - Fair
C - Poor

TABLE A-XXX

RANGE OF FINENESS MODULUS IN CONCRETE BATCH, WRIGHT PAVING JOB

Mix Time (Seconds)	Replication	Range of Fineness Modulus Among Positions	Visual Classification of Uniformity*
60	2	1.12	A
30	1	.52	A
45	2	.34	A
120	2	.28	A
45	1	.25	A
60	1	.20	A
180	1	.20	A
120	1	.15	A
30	2	.12	A
180	2	.10	A

*A - Well mixed
B - Fair
C - Poor

TABLE A-XXXI

RANGE OF CEMENT CONTENT PER GRAM OF MORTAR IN
A CONCRETE BATCH, WRIGHT PAVING JOB

Mix Time (Seconds)	Replication	Range of Cement Content Among Positions (Grams Cement per Gram Mortar)	Visual Classification of Uniformity*
30	1	.06	A
60	1	.05	A
180	1	.05	A
180	2	.04	A
45	1	.03	A
120	1	.03	A
30	2	.03	A
45	2	.02	A
60	2	.02	A
120	2	.02	A

*A - Well mixed
B - Fair
C - Poor

TABLE A-XXXII

COMPRESSIVE STRENGTHS AND VISUAL CLASSIFICATION OF CONCRETE SAMPLES, MACDOUGALD PAVING JOB

Mix Time (Seconds)	Sample Number Replication	Sample Number Position	Compressive Strength (Lb/Sq In)	Degree of Mixing*
45	1	3	5550	A
45	1	2	5450	A
45	1	1	5390	A
30	1	2	5170	B
120	2	2	4870	A
180	2	1	4760	A
60	2	1	4650	A
120	2	3	4640	A
180	2	2	4630	A
60	2	2	4530	A
180	2	3	4430	A
120	2	1	4420	A
60	1	2	4260	A
45	2	2	4200	A
60	1	3	4140	A
60	1	1	4120	A
45	2	1	4040	A
30	1	1	4030	B
60	2	3	3980	A
45	2	3	3940	A
180	1	2	3580	A
180	1	3	3530	A
180	1	1	3340	A
30	1	3	3330	B
120	1	3	3140	A
30	2	3	3050	A
30	2	1	3000	A
120	1	1	2780	A
30	2	2	2730	A
120	1	2	1900	A

*A - Well mixed
B - Fair
C - Poor

TABLE A-XXXIII

RANGE OF COMPRESSIVE STRENGTHS IN CONCRETE BATCH, MACDOUGALD PAVING JOB

Mix Time (Seconds)	Replication	Range of Compressive Strength Among Positions (Lb/Sq In)	Visual Classification of Uniformity*
30	1	1840	B
120	1	1240	A
60	2	670	A
120	2	450	A
180	2	330	A
30	2	320	A
45	2	260	A
180	1	240	A
45	1	160	A
60	1	140	A

*A - Well mixed
B - Fair
C - Poor

TABLE A-XXXIV

RANGE OF FINENESS MODULUS IN CONCRETE BATCH, MACDOUGALD PAVING JOB

Mix Time (Seconds)	Replication	Range of Fineness Modulus Among Positions	Visual Classification of Uniformity*
45	2	.58	A
60	2	.42	A
30	2	.31	A
30	1	.27	B
180	1	.26	A
120	1	.20	A
120	2	.17	A
45	1	.16	A
180	2	.10	A
60	1	.09	A

*A - Well mixed
B - Fair
C - Poor

TABLE A-XXXV

RANGE OF CEMENT CONTENT PER GRAM OF MORTAR WITHIN CONCRETE BATCH, MACDOUGALD PAVING JOB

Mix Time (Seconds)	Replication	Range of Cement Content Among Positions (Grams of Cement per Gram of Mortar)	Visual Classification of Uniformity*
45	2	.06	A
30	1	.04	B
120	1	.02	A
30	2	.02	A
60	2	.02	A
45	1	.01	A
60	1	.01	A
180	1	.01	A
120	2	.01	A
180	2	.01	A

*A - Well mixed
B - Fair
C - Poor

TABLE A-XXXVI

COMPRESSIVE STRENGTHS AND VISUAL CLASSIFICATION
OF CONCRETE SAMPLES MACDOUGALD WARREN, INCORPORATED

Mix Time (Seconds)	Sample Number Replication	Position	Compressive Strength (Lb/Sq In)	Degree of Mixing*
60	1	1	6230	A
45	3	1	6170	A
30	1	1	5850	A
30	2	1	5420	A
30	3	1	5390	B
45	2	2	5370	A
45	1	1	5210	A
60	1	2	5210	A
120	1	1	5180	A
30	2	2	5110	A
45	2	1	5050	A
60	2	1	5040	A
45	1	2	4980	A
60	2	2	4880	A
180	1	1	4730	A
120	1	2	4720	A
45	3	2	4650	A
30	3	2	4380	B
45	1	3	4360	A
180	1	3	4330	A
45	2	3	4220	A
30	1	2	4210	A
180	1	2	3980	A
120	1	3	3890	A
60	1	3	3880	A
120	2	1	3830	A
60	2	3	3760	A
120	3	1	3750	A
120	2	3	3600	A
180	2	1	3570	A
180	3	2	3390	A
120	2	2	3300	A
120	3	2	3290	A
180	3	1	3270	A
45	3	3	3250	A
30	2	3	3230	A
60	3	1	3220	A
60	3	3	3220	A

(Continued)

TABLE A-XXXVI (Continued)

COMPRESSIVE STRENGTHS AND VISUAL CLASSIFICATION
OF CONCRETE SAMPLES MACDOUGALD WARREN, INCORPORATED

Mix Time (Seconds)	Sample Number Replication	Sample Number Position	Compressive Strength (Lb/Sq In)	Degree of Mixing*
60	3	2	3040	A
180	2	3	3000	A
180	3	3	3000	A
180	2	2	2810	A
30	1	3	2650	A
120	3	3	2560	A
30	3	3	2190	B

*A - Well mixed
B - Fair
C - Poor

TABLE A-XXXVII

RANGE OF COMPRESSIVE STRENGTH IN CONCRETE BATCH,
MACDOUGALD WARREN, INCORPORATED

Mix Time (Seconds)	Replication	Range of Compressive Strength Among Positions (Lb/Sq In)	Visual Classification of Uniformity*
30	1	3200	A
30	3	3200	B
45	3	2920	A
60	1	2350	A
30	2	2190	A
120	1	1290	A
60	2	1280	A
120	3	1190	A
45	2	1150	A
45	1	850	A
180	2	760	A
180	1	750	A
120	2	530	A
180	3	390	A
60	3	180	A

*A - Well mixed
B - Fair
C - Poor

TABLE A-XXXVIII

RANGE OF FINENESS MODULUS IN CONCRETE BATCH,
MACDOUGALD WARREN, INCORPORATED

Mix Time (Seconds)	Replication	Range of Fineness Modulus Among Samples	Visual Classification of Uniformity*
180	2	0.99	A
120	3	0.95	A
30	1	0.61	A
45	2	0.47	A
30	3	0.43	B
60	1	0.37	A
60	3	0.32	A
30	2	0.31	A
60	2	0.29	A
45	1	0.27	A
45	3	0.23	A
120	1	0.16	A
180	1	0.13	A
180	3	0.12	A
120	2	0.11	A

*A - Well mixed
B - Fair
C - Poor

TABLE A-XXXIX

RANGE OF CEMENT CONTENT WITHIN CONCRETE BATCH,
MACDOUGALD WARREN, INCORPORATED

Mix Time (Seconds)	Replication	Maximum Variation Among Position (Gram of Cement per Gram of Mortar)	Visual Classification of Uniformity*
45	3	.22	A
30	3	.14	B
60	1	.13	A
120	3	.12	A
120	1	.09	A
45	2	.08	A
60	3	.08	A

(Continued)

TABLE A-XXXIX (Continued)

RANGE OF CEMENT CONTENT WITHIN CONCRETE BATCH,
MACDOUGALD WARREN, INCORPORATED

Mix Time (Seconds)	Replication	Maximum Variation Among Position (Gram of Cement per Gram of Mortar)	Visual Classification of Uniformity*
180	1	.07	A
60	2	.07	A
180	2	.07	A
30	2	.06	A
30	1	.05	A
180	3	.05	A
45	1	.04	A
120	2	.04	A

*A - Well mixed
B - Fair
C - Poor

TABLE A-XL

COMPRESSIVE STRENGTHS AND VISUAL CLASSIFICATION
OF CONCRETE SAMPLES, GEORGIA TECH MIXER

Mix Time (Seconds)	Sample Number		Compressive Strength (Lb/Sq In)	Degree of Mixing*
	Replication	Position		
180	1	1	3870	A
30	2	3	3760	A
45	3	1	3750	A
30	1	1	3630	A
180	1	2	3560	A
45	3	2	3530	A
45	3	3	3520	A
180	2	1	3470	A
180	2	3	3470	A
30	3	3	3450	A
30	1	3	3430	A
60	1	1	3420	A
120	1	1	3410	A
45	2	2	3400	A

(Continued)

TABLE A-XL (Continued)

COMPRESSIVE STRENGTHS AND VISUAL CLASSIFICATION
OF CONCRETE SAMPLES, GEORGIA TECH MIXER

Mix Time (Seconds)	Sample Number: Replication	Sample Number: Position	Compressive Strength (Lb/Sq In)	Degree of Mixing*
120	3	2	3360	A
180	1	3	3330	A
180	3	1	3310	A
60	2	1	3310	A
60	3	3	3280	A
180	2	2	3270	A
120	3	1	3270	A
30	1	2	3240	A
45	2	1	3230	A
60	2	3	3220	A
180	3	3	3170	A
30	3	1	3110	A
180	3	2	3090	A
60	1	3	3000	A
60	1	2	2910	A
30	2	2	2870	A
60	2	2	2860	A
45	1	1	2820	A
45	1	3	2820	A
120	1	3	2820	A
30	2	1	2810	A
60	3	1	2800	A
120	1	2	2770	A
30	3	2	2740	A
45	1	2	2730	A
120	2	2	2730	A
120	2	3	2640	A
120	2	1	2580	A
120	3	3	2090	A
45	2	3	2060	A
60	3	2	2060	A

*A - Well mixed
B - Fair
C - Poor

TABLE A-XLI

RANGE OF COMPRESSIVE STRENGTHS IN CONCRETE BATCH, GEORGIA TECH MIXER

Mix Time (Seconds)	Replication	Range of Compressive Strength Among Positions (Lb/Sq In)	Visual Classification of Uniformity*
45	2	1340	A
120	3	1270	A
60	3	1220	A
30	2	950	A
30	3	710	A
120	1	640	A
180	1	540	A
60	1	510	A
60	2	450	A
30	1	390	A
45	3	230	A
180	3	220	A
180	2	200	A
120	2	150	A
45	1	90	A

*A - Well mixed
B - Fair
C - Poor

TABLE A-XLII

RANGE OF FINENESS MODULUS IN CONCRETE BATCH, GEORGIA TECH MIXER

Mix Time (Seconds)	Replication	Range of Fineness Modulus Among Samples	Visual Classification of Uniformity*
120	1	.65	A
45	2	.59	A
180	1	.32	A
30	3	.30	A
30	1	.29	A
60	1	.25	A
180	2	.25	A
30	2	.21	A
45	1	.18	A
60	2	.14	A

(Continued)

TABLE A-XLII (Continued)

RANGE OF FINENESS MODULUS IN CONCRETE BATCH, GEORGIA TECH MIXER

Mix Time (Seconds)	Replication	Range of Fineness Modulus Among Samples	Visual Classification of Uniformity*
120	3	.11	A
60	3	.09	A
120	2	.07	A
180	3	.06	A
45	3	.04	A

*A - Well mixed
B - Fair
C - Poor

TABLE A-XLIII

RANGE OF CEMENT CONTENT PER GRAM OF MORTAR IN A CONCRETE BATCH, GEORGIA TECH MIXER

Mix Time (Seconds)	Replication	Range of Cement Content Among Positions (Gram of Cement per Gram of Mortar)	Visual Classification of Uniformity*
60	1	.05	A
45	1	.04	A
120	1	.04	A
180	1	.03	A
180	2	.02	A
30	3	.02	A
60	3	.02	A
180	3	.02	A
30	1	.01	A
30	2	.01	A
60	2	.01	A
120	2	.01	A
45	3	.01	A
120	3	.01	A
45	2	.00	A

*A - Well mixed
B - Fair
C - Poor

TABLE A-XLIV

COMPRESSIVE STRENGTHS AND VISUAL CLASSIFICATION OF CONCRETE SAMPLES, CAMPBELL MATERIALS COMPANY

Mix Time (Seconds)	Sample Number: Replication	Sample Number: Position	Compressive Strength (Lb/Sq In)	Degree of Mixing*
45	2	1	6640	C
45	1	1	6540	B
45	2	2	5920	C
60	1	1	5830	C
120	2	2	5160	A
120	2	1	4890	A
45	1	3	4850	A
45	1	2	4840	A
45	2	3	4620	B
120	2	3	4590	A
180	1	2	4380	A
180	1	3	4250	A
60	1	2	4210	B
120	1	1	4130	A
60	1	3	4030	A
180	1	1	4010	A
120	1	2	3820	A
120	1	3	3730	A

*A - Well mixed
B - Fair
C - Poor

TABLE A-XLV

RANGE OF COMPRESSIVE STRENGTHS IN CONCRETE BATCH, CAMPBELL MATERIALS COMPANY

Mix Time (Seconds)	Replication	Range of Compressive Strengths Among Positions (Lb/Sq In)	Visual Classification of Uniformity*
45	2	2020	C
60	1	1800	B
45	1	1700	A
120	2	570	A
120	1	400	A
180	1	270	A

*A - Well mixed
B - Fair
C - Poor

TABLE A-XLVI

RANGE OF FINENESS MODULUS IN A CONCRETE BATCH, CAMPBELL MATERIALS COMPANY

Mix Time (Seconds)	Replication	Range of Fineness Modulus Among Samples	Visual Classification of Uniformity*
45	1	.31	A
45	2	.23	C
60	1	.15	B
180	1	.07	A
120	1	.02	A
120	2	.01	A

*A - Well mixed
B - Fair
C - Poor

TABLE A-XLVII

RANGE OF CEMENT CONTENT PER GRAM OF MORTAR IN A CONCRETE BATCH, CAMPBELL MATERIALS COMPANY

Mix Time (Seconds)	Replication	Range of Cement Content Among Positions (Gram of Cement per Gram of Mortar)	Visual Classification of Uniformity*
45	1	.15	A
60	1	.11	B
120	1	.10	A
45	2	.10	C
180	1	.06	A
120	2	.02	A

*A - Well mixed
B - Fair
C - Poor

VII. APPENDIXES (Continued)

APPENDIX B

CONCRETE MIXER SPECIFICATIONS

Figure B-1. Specifications of Mixers for Wright Contracting Company and MacDougald Construction Company.

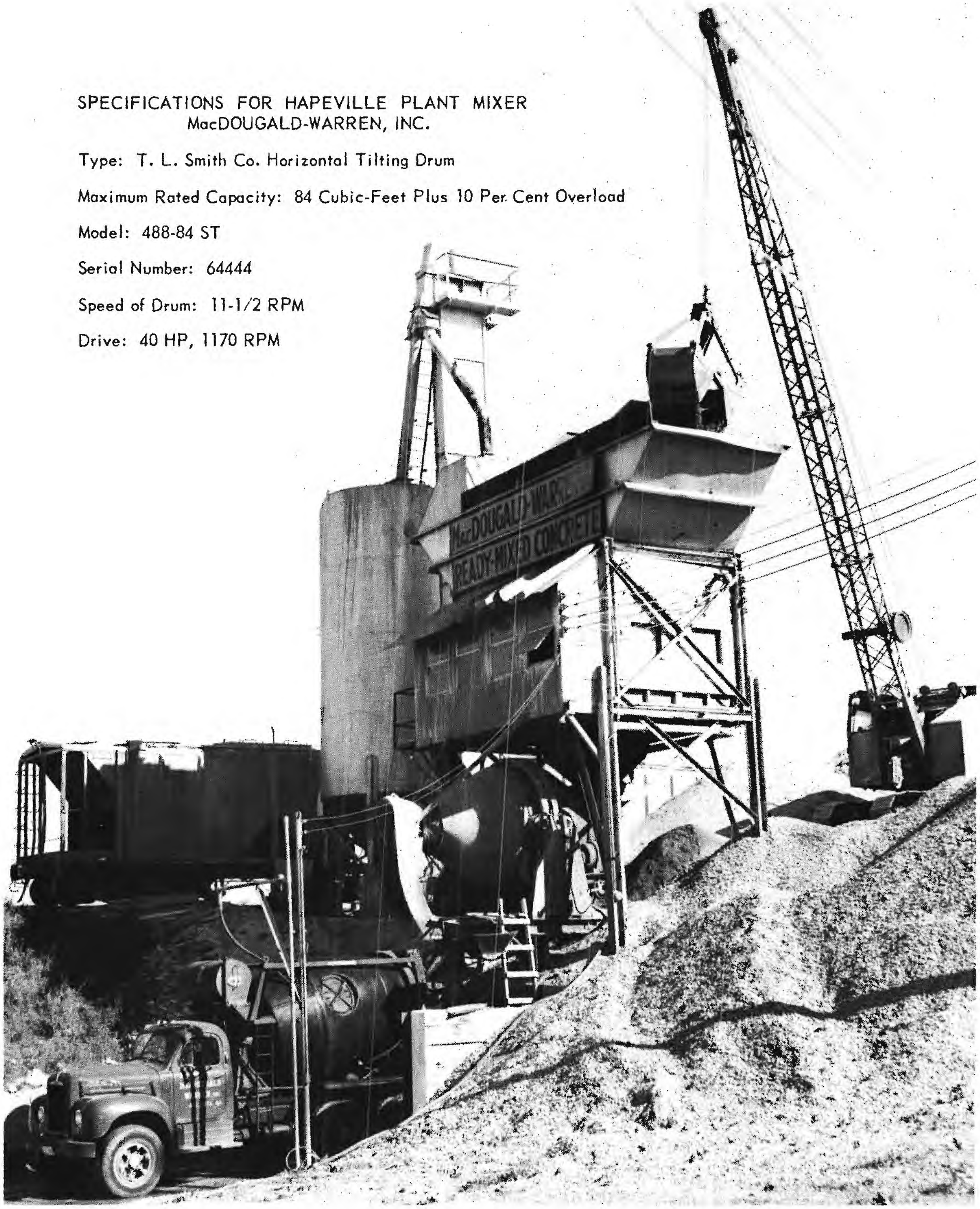

Figure B-2. Specifications for Hapeville Plant Mixer, MacDougald Warren, Incorporated.

SPECIFICATIONS FOR GEORGIA TECH LABORATORY MIXER

Type: Worthington

Maximum Rated Capacity: 6 Cubic-Feet Pulus 10% Overload

Model: 6S–2A

Serial No.: W59644

Speed of Drum: 18 RPM

Drive: 16 HP, 1750 RPM

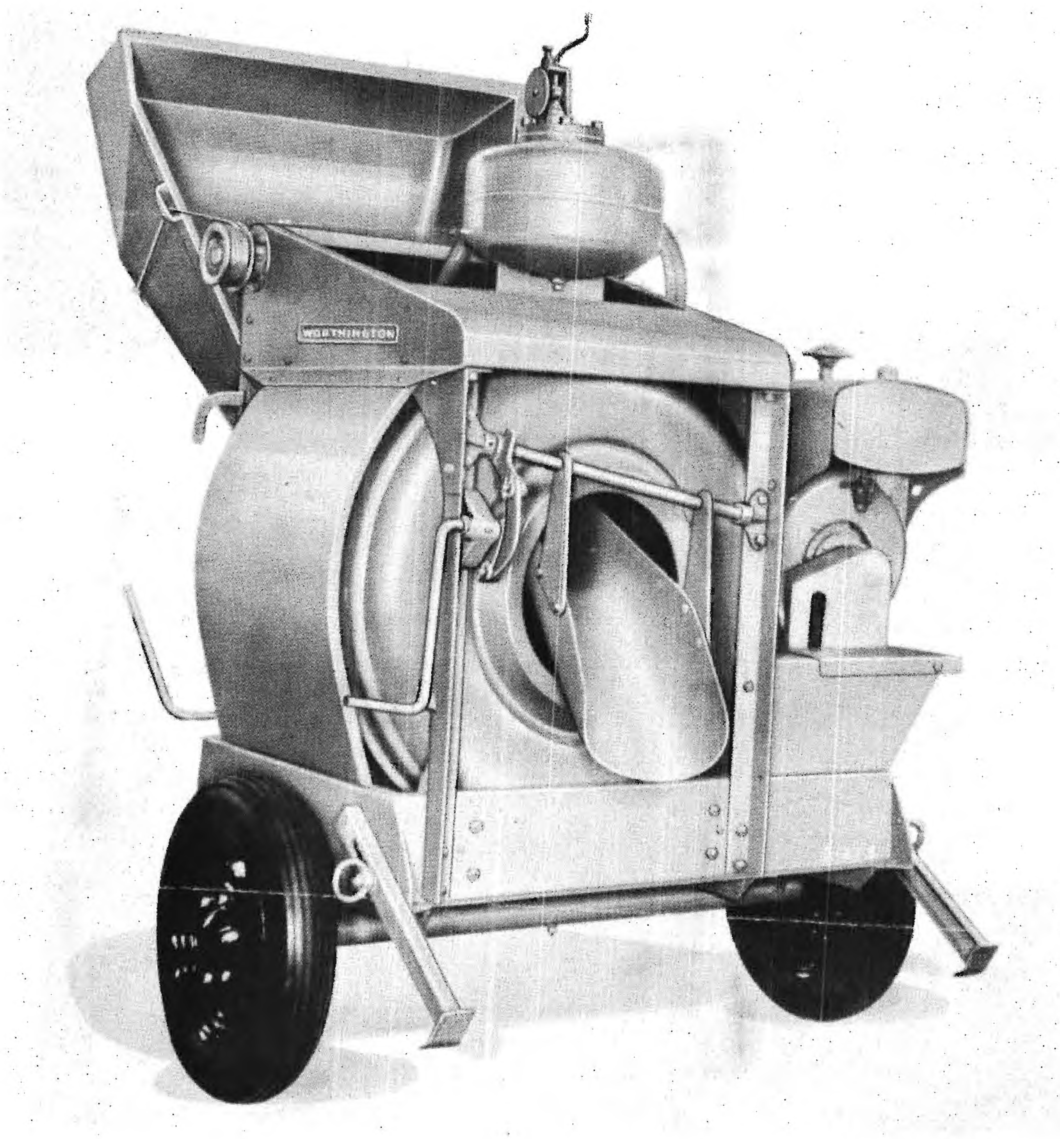

Figure B-3. Georgia Institute of Technology's Concrete Laboratory Mixer.

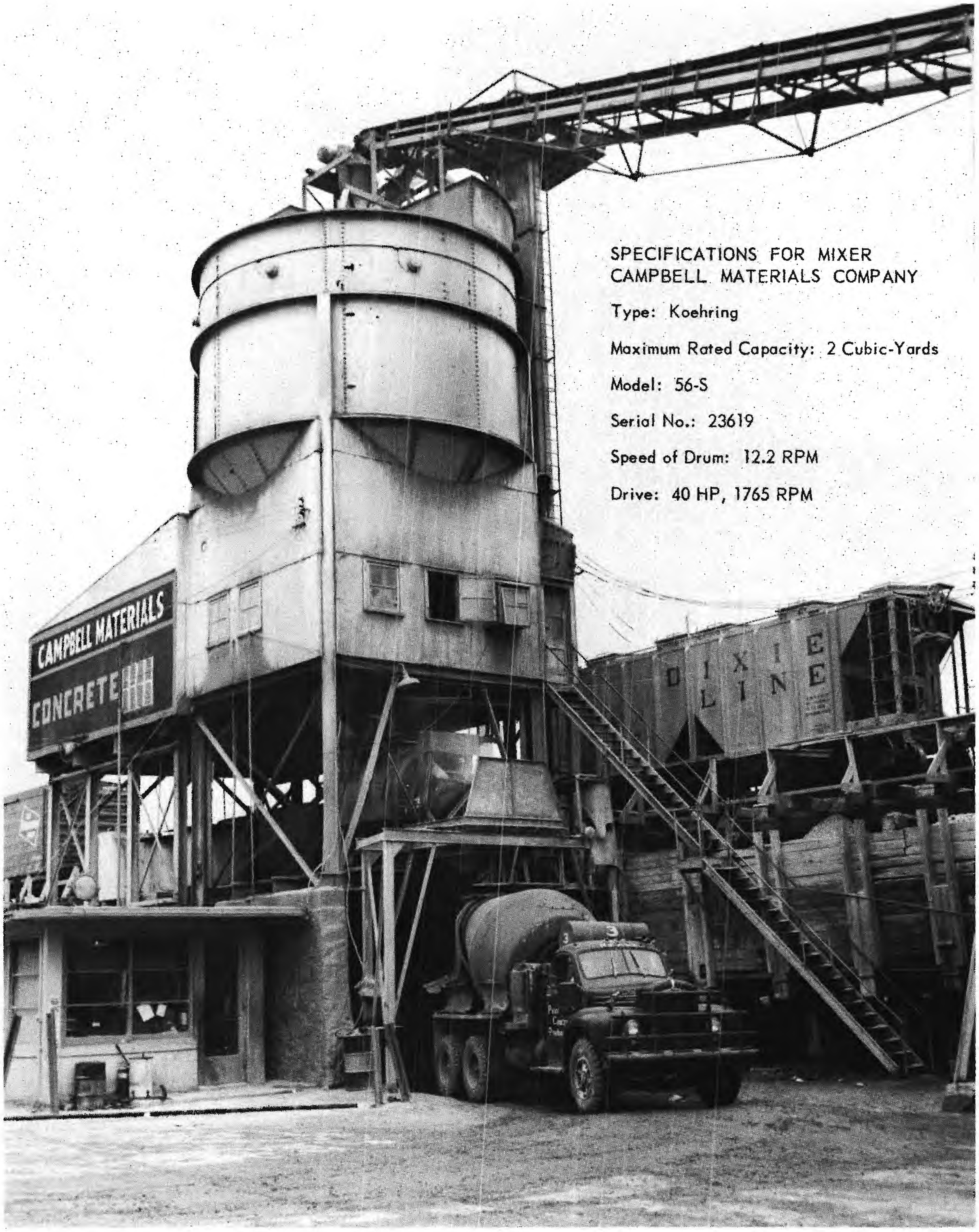

Figure B-4. Specifications for Mixer, Campbell Materials Company.

VII. APPENDIXES (Continued)

APPENDIX C

DATA SHEET USED IN PROCESSING AND TESTING OF SAMPLES

TABLE C-I

DATA SHEET USED IN PROCESSING AND TESTING OF SAMPLES

Uniformity of Concrete Mix
Date:____________________

Type Mixer:_________________________
Site:_______________________________

Concrete Specifications:____________________
Volume Mixed:_________________
Mixing Time:________Seconds

Sample:__________________
Replication:_____________

Visual Classification

Poor______Fair______Well______

Compressive Strength Test

Cylinder No.:________Testing Date:__________28-Day Failure Load:__________
Compressive Strength:____________Lb/Sq In

Cement Content by Neutron Activation

Mortar Sample No.	Corrected Sample Count Channels 62-74	Cement Content (Grams) See Fig. 11	Net Sample Weight (Grams)	Cement-Mortar Ratio (Grams Cement Per Gram Mortar)
______	______	______	______	______
______	______	______	______	______

Sieve Analysis

Total Weight of Sample:___________Grams, Weight of Split:_________Grams

Sieve Size:	Weight Retained	Cumulative Weight Retained	Cumulative Per Cent Retained
# 1 1/2	______	______	______
3/4	______	______	______
3/8	______	______	______
4	______	______	______
8	______	______	______
16	______	______	______
30	______	______	______
50	______	______	______
100	______	______	______
		Fineness Modulus	______
# 1	______	______	
1/2	______	______	
200	______	______	
Pan	______	______	

VII. APPENDIXES (Continued)

APPENDIX D

DATA FOR COUNT RATE VERSUS WEIGHT OF CEMENT CHART (FIGURE 12)

TABLE D-I

5-MINUTE COUNTS RECORDED FOR CEMENT MORTAR STANDARDS

Cement Content (Grams)	Normalized Counts Recorded, Channels 62-74 1	2	3
0.6	723	641	702
0.8	959	898	898
1.0	1159	1126	1218
1.2	1310	1379	1378
1.4	1572	1630	1688
1.6	1830	1774	1773
1.8	1967	2042	2073

VII. APPENDIXES (Continued)

APPENDIX E

EXAMPLE CALCULATION FOR DETERMINING CEMENT CONTENT OF MORTAR SAMPLES

TABLE E-I

EXAMPLE CALCULATION IN DETERMINING CEMENT CONTENT OF MORTAR SAMPLES

Sample Number	Indium Foil Data: Foil Count Per 5 Minutes	Foil Count Per Seconds	True Count N_t (Per Second)	Foil Weight (Mg)	N_t Per 20 Mg
334	77,039	257	299	20.1	298

Sample Number	Mortar Sample Data: Sample Count Channels 62-74	Sample Count for N_t=300 (Normalized)	Sample Weight (Grams)	Container Weight (Grams)	Net Sample Weight (Grams)	Weight Cement* (Grams)	Cement Content (Grams Cement Per Gram Mortar)
334	1301	1310	5.18	0.94	4.24	1.14	0.27

*See Figure 12.

VII. APPENDIXES (Continued)

APPENDIX F

SCINTILLATION CRYSTAL MOUNTING AND SAMPLE HOLDER

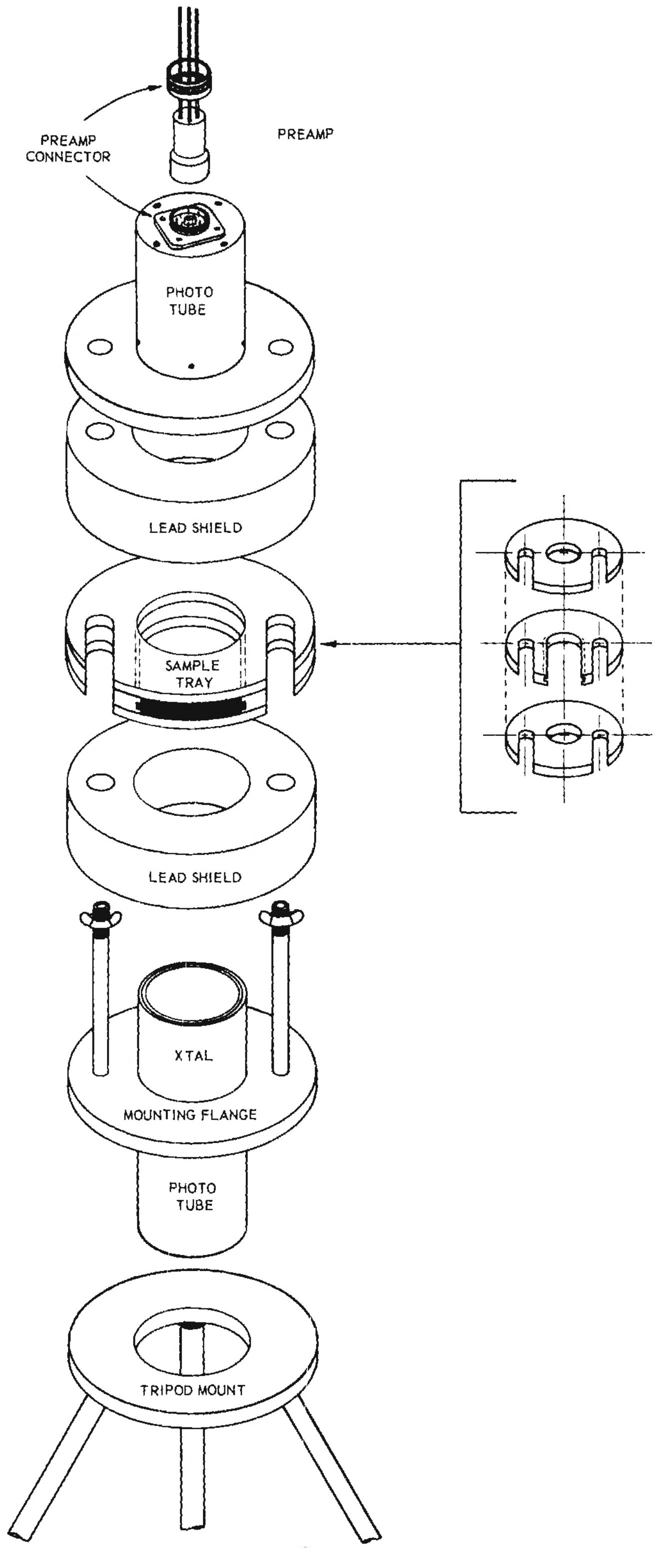

Figure F-1. Scintillation Crystal Mounting and Sample Holder.

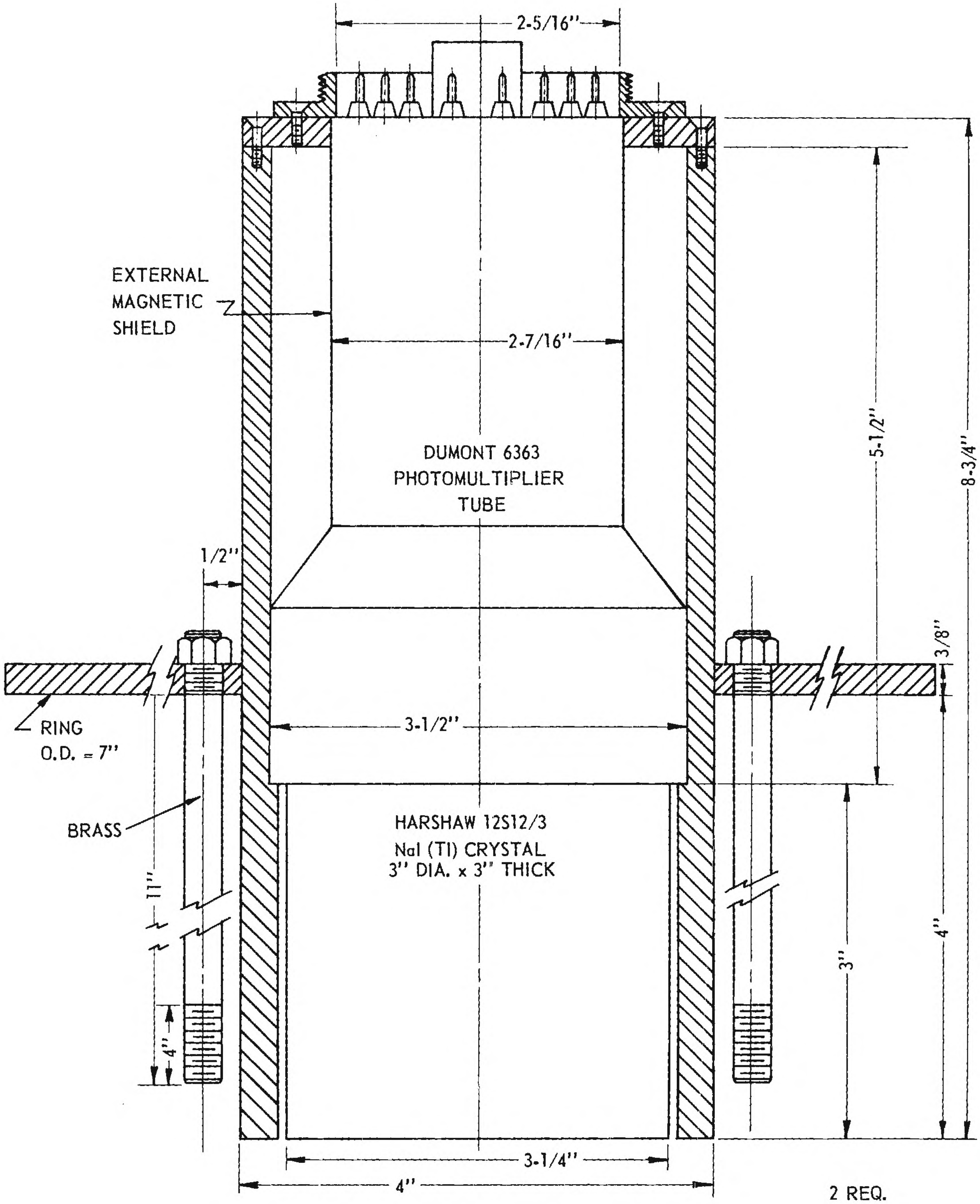

Figure F-2. Detail of Sodium Iodide (Thallium) Crystal.

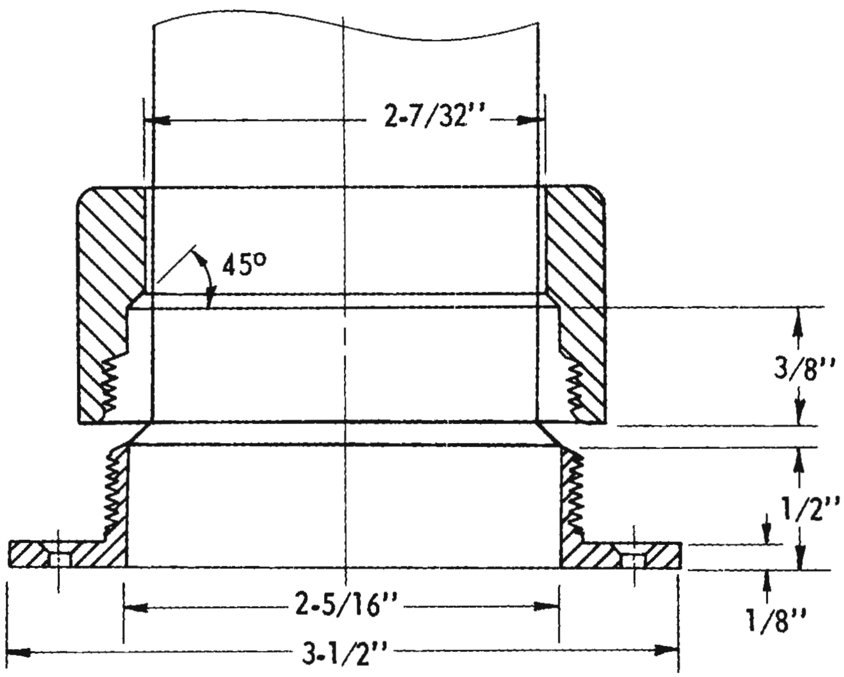

Figure F-2 (Continued). Detail of Sodium Iodide (Thallium) Crystal.

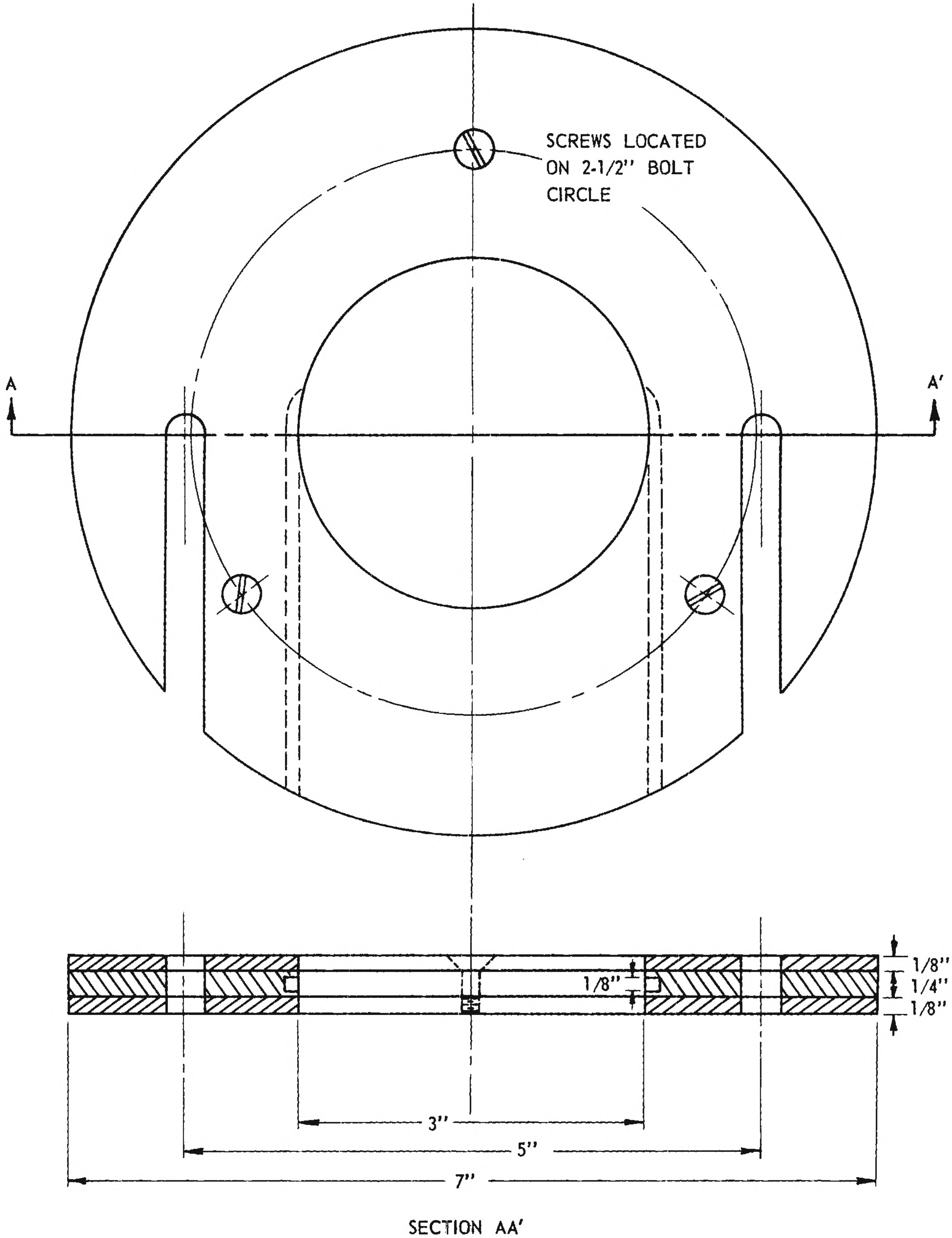

Figure F-3. Detail of Upper Mounting Ring.

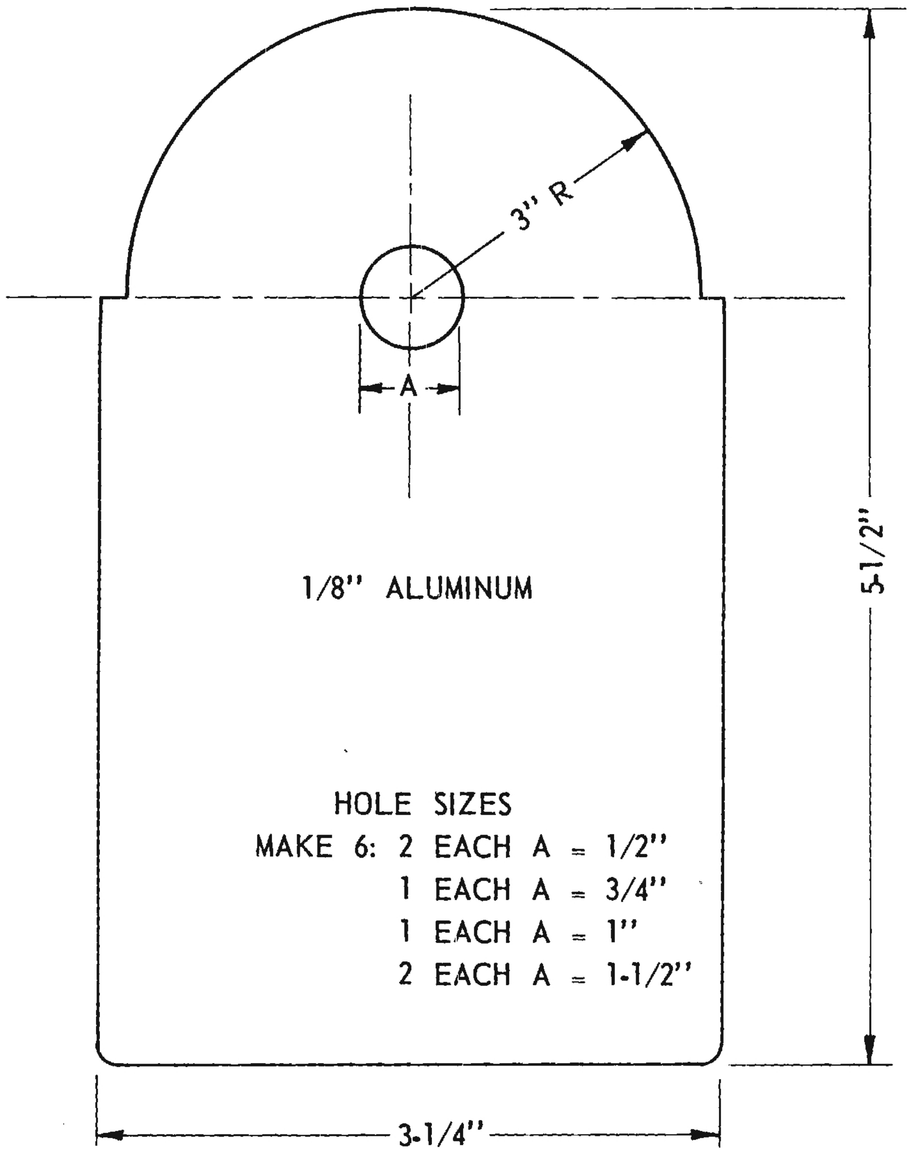

Figure F-4. Detail of Sample Holder.

VII. APPENDIXES (Concluded)

APPENDIX G

CRITERIA FOR THE VISUAL EVALUATION OF CONCRETE MIXING ADEQUACY

TABLE G-I

CRITERIA FOR THE VISUAL EVALUATION OF UNIFORMING OF MIXING OF CONCRETE SAMPLES

Well-mixed	Uniform dispersion of batch constituents.
	Proper workability.
Fair	Uniform dispersion of cement and coarse and fine aggregate.
	Dry or excessively wet, giving non-uniform workability.
Poor	Segregation of one or more constituents of the batch.
	Dry or excessively wet, giving non-uniform workability.

SRO-79

FINAL REPORT

PROJECT NO. A-446-7

DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOISOTOPES

(Final Technical Report for That Phase of the Program Dealing with Bituminous Concrete)

BY

Paul K. Howard and Donald O. Covault

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FINAL REPORT

PROJECT NO. A-446-7

DETERMINATION OF THE UNIFORMITY OF MIXING OF PORTLAND CEMENT AND BITUMINOUS CONCRETE FOR VARIOUS MIXING TIMES BY THE USE OF RADIOISOTOPES

(Final Technical Report for That Phase of the Program Dealing with Bituminous Concrete)

By

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ABSTRACT

Uniformity of mixing is a good criterion by which to judge the quality of a bituminous concrete mix and mixing adequacy. In this research, mineral filler content of bituminous concrete mortar, fineness modulus of aggregate, and Hveem stability were used to indicate the uniformity of the mixed bituminous concrete. Fineness modulus and Hveem stability were determined by conventional methods.

An attempt was made to determine mineral filler content of bituminous concrete mortar samples by neutron activation analysis of calcium-49 produced in the calcium in the mineral filler. Determination of mineral filler content was not possible using the Georgia Tech Van de Graaff Accelerator and a beryllium target. The authors believe that a neutron source producing a higher neutron flux, such as a reactor or some other neutron generator, would make the method possible.

Mixing times of 30 seconds or greater had no effect on the uniformity of mixing as measured by Hveem stability, fineness modulus or calcium count. However, differences from batch to batch were very significant for Hveem stability and less significant for fineness modulus and calcium count. Position and interactions have no effect on the uniformity of mixing.

Neutron backscatter techniques did not prove feasible as a testing method for determining asphaltic cement content of in-place bituminous concrete pavements. However, neutron attenuation techniques did appear feasible for this determination using controlled testing environment.

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CHAPTER I

INTRODUCTION

General Remarks

Consumption

In 1961, 74 per cent of all domestic shipments of petroleum asphalts were used for paving products. (1)* This amounted to more than 15 million short tons and was used to construct many miles of new roads and streets as well as resurface and patch old facilities. The construction and maintenance required an expenditure of millions of dollars at all levels of government. As with any expenditure of public funds, attention was closely directed to quality of product received.

Measures of Quality

The measures of quality of interest for bituminous concrete mixtures are stability, durability, flexibility, resistance to skidding, and workability. Techniques are available at the design stage to insure mixtures meeting quality specifications, but the specifications are often difficult to achieve in the field with present construction practices. The difficulties arise in three areas: proportioning the mix constituents; mixing the constituents to uniformity; and placing the mix on the roadway.

Scope of Research

This research has been concerned with the problem of mixing the bituminous concrete constituents to obtain uniformity. Activation analysis

*Number indicated refers to listed number of the publication in the bibliography.

was used to determine the dispersion of mineral filler throughout the mix as a measure of uniformity of mixing. Stability of the mix and aggregate fineness modulus were determined and compared to the dispersion results.

An investigation was conducted to determine the feasibility of using radiosotopes to determine asphaltic cement content of in-place bituminous concrete. The method investigated was thermal neutron backscatter, which has been used successfully to determine moisture content of soil and other materials.

Testing Methods to Determine Mixing Uniformity

Background

All bituminous pavement mix design methods are predicated on the assumption that field production methods will produce a uniform mixture. With increasing use of bituminous materials in highway construction it is becoming more and more important to develop a simple procedure for testing for uniformity of mix. Producers of bituminous concrete mixes are vitally interested in the mixing time required to produce a uniform mixture because of the highly competitive marketing of their products as reflected by cost of product.

Present Methods

Methods now available for testing a batch for uniformity require determination of mix properties at various points within the batch. Comparison among the points indicates degree of mixing of the batch. The mix properties used would be stability, gradation and asphaltic cement content.

Stability

Stability, defined as resistance to displacement, is one of the most important properties required of a bituminous mixture. (2) Stability depends on the interlocking or internal friction of the aggregate particles and the cohesion of the cementing agent. There are many methods for measuring stability such as the Hubbard-Field stability test, unconfined-compression test, Marshall test, Hveem Stabilometer, and triaxial-compression test. While each of these tests indicates a relative stability, each test also indicates effects particular to the individual test method.

Gradation

Gradation is the particle size distribution of the aggregate. It is expressed as per cent by weight of aggregate passing a series of sieves of standard sized openings. The gradation of a bituminous concrete sample can be determined only after the asphaltic cement has been extracted from the aggregate.

Gradation can also be expressed as aggregate fineness modulus in order to reduce the amount of data required to describe a sieve analysis. To find the fineness modulus, the percentage of material coarser than a specific series of sieves is calculated, and the sum of these percentages divided by 100 is the fineness modulus.

Asphaltic Cement Content

Asphaltic cement content is expressed as the per cent of asphaltic cement by weight of total mix. The standard method for determining asphaltic cement content involves weighing the mix sample, extracting the asphaltic cement with trichloroethane, and drying and weighing the free aggregate. The difference thus determined is weight of asphaltic cement and is used to calculate asphaltic cement content.

Uniformity of Mix

Comparisons among positions within a batch using stability, fineness modulus, or asphaltic cement content indicate degree of mixing or uniformity of mix for the batch.

Mineral Filler Content

The dispersion of mineral filler throughout the mix, in addition to the method described above using stability and fineness modulus, was used to determine uniformity of mixing. Dispersion of mineral filler was measured by comparing mineral filler content as determined by activation analysis. Comparisons were made among the various positions and mixing times.

The mineral filler, in this case a powdered limestone produced by the Georgia Marble Company, contained essentially the same constituents as portland cement. As in that phase of the program dealing with portland cement concrete, (see reference 3) calcium-48, present in the mineral filler, was chosen as a suitable element for activation analysis.

Hot-Mix Plants

Plant designs are of two types: continuous or batch. The continuous hot-mix plant maintains a steady input of aggregate, asphaltic cement and mineral filler to the mixer with a steady output of bituminous concrete. The hot-mix batch plant receives the input in a batch, mixes the constituents, and dumps the output in a batch.

The batch plant is most common of the types of mixers used for bituminous concrete production. For this reason and because of the difficulty of sampling a continuous plant, the batch plant was chosen to be sampled in this project.

The plant sampled was a Cedar Rapids G-40, a 4000 pound batch plant, located just south of Tyrone, Georgia, on State Route 74. The plant was owned by the McIntosh Paving Company.

Because of the large amount of dust created by a hot-mix batch plant it was not possible to use the radioactive tracer method to evaluate uniformity of mixing of the mineral filler. Neutron activation was chosen as an alternative method as described in the Annual Report No. 1 of this project. (3)

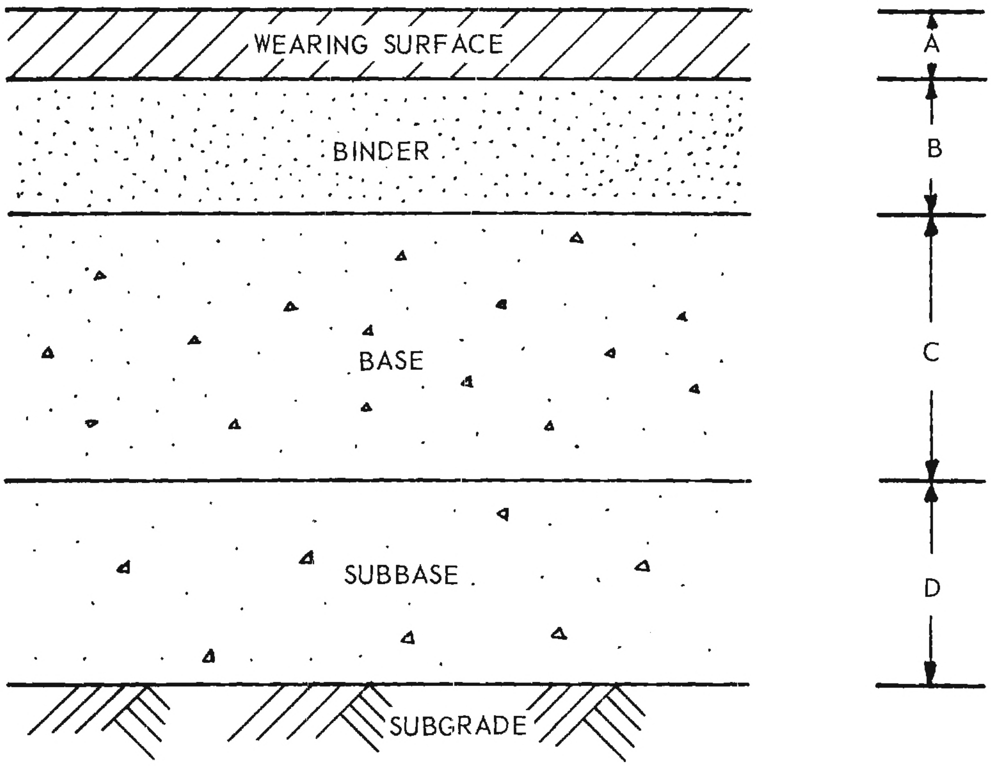
CHAPTER II

INVESTIGATION OF THE FEASIBILITY OF THE MEASUREMENT OF ASPHALTIC CEMENT CONTENT BY NEUTRON BACKSCATTER TECHNIQUES

Background

Under present construction practices, bituminous concrete is usually produced at a plant, transported to the construction site in trucks and placed in the roadway. Without creating delays, the mix should be tested for asphaltic cement content at some point in the process. Highly desirable from the standpoint of the construction contractor and the contracting agency would be a test method which would test for asphaltic cement content of the in-place pavement. The desirable test method should be simple, fast, and reliable. It should measure the asphaltic cement content of the compacted pavement which is placed in 1 to 3 inch lifts.

Figure 1 is a sketch of a typical cross section of bituminous concrete pavement. The wearing surface is a fine graded high density bituminous concrete whose asphaltic cement content is usually between 4 and 9 per cent. The binder is usually a medium graded bituminous concrete containing from 3 to 7 per cent asphaltic cement. If a base is included in the pavement design, it may or may not contain asphaltic cement depending on the material available and stability requirements. The subbase is usually compacted gravel or crushed stone which transfers the load to the subgrade. The subgrade is the natural in-place material which must support the pavement structure and its loads.



LIFT	DEPTH	MATERIAL
A	1-1/2" TO 3"	BITUMINOUS CONCRETE
B	1-1/2" TO 3"	BITUMINOUS CONCRETE
C	3" TO 6"	BITUMINOUS CONCRETE, GRAVEL, CRUSHED STONE
D	AS REQUIRED	GRAVEL OR CRUSHED STONE

Figure 1. Typical Cross Section of Bituminous Concrete Pavement.

There is in present use a method for determining the moisture content and density of a soil which meets the requirements of an asphaltic cement content test as mentioned above. This method employs the principles of neutron thermalization and thermal neutron backscatter for moisture content measurement and gamma backscatter for density measurements.

Neutron backscatter requires an emitter of high energy neutrons, a material capable of thermalizing the neutrons, and an efficient system for counting thermal neutrons. Neutrons from the emitter enter the material being tested and lose much of their energy in collision. The thermal neutrons are not counted until their random motion carries them back to the detection system. Using this technique, the actual characteristic measured is the ability of the material to thermalize neutrons. Materials with high hydrogen content are good neutron thermalizers and backscatter count varies with the hydrogen content. (4)

The Model P-21 surface moisture probe and the Model 2800 portable scaler, both made by Nuclear-Chicago, were used in an attempt to determine asphaltic cement content of bituminous concrete by backscatter count. Asphaltic cement is hydrocarbon of high hydrogen content. With the exception of water, present in amounts much less than one per cent by weight, bituminous concrete contains no other hydrogen bearing constituents immediately after being produced in a hot-mix plant.

Effects of Depth, Surface Area of a Square Sample and Backing Material

Tests were conducted to determine the effects of three different variables on asphaltic cement content as measured by backscatter count. These variables were sample depth, surface area of a square sample, and sample backing material.

To test for the effect of sample depth on the backscatter count, bituminous concrete samples were constructed using local aggregates and grade AC-8 asphaltic cement. Sample depth was varied from 1 inch to 11 inches. For this test the lateral sample dimensions were 24 inches long by 24 inches wide as recommended by Nuclear-Chicago. All samples were tested on a metal backing which was 3 feet above a concrete floor.

Results of this series of tests were normalized to a standard background and are presented in Figure 2. This figure indicates that at sample depths of less than 10 inches, depth has a significant effect on the count rate. Depths greater than 10 inches act as infinite depths, while at depths less than 10 inches the count varies in a nonlinear manner decreasing with the depth.

The effect of surface area of square samples on the backscatter count was determined by maintaining the sample depth at 4 inches while varying the surface area from 576 square inches to 196 square inches. A sample depth of 4 inches was chosen to approximate the usual life depth of bituminous pavement construction. Results of this test indicated that a square sample surface area of 324 square inches or less had an effect on the backscatter count. The results of this test are shown in Figure 3.

For samples of less than 10 inches in depth, sample backing material was found to have a significant effect on backscatter count rate. This test was conducted by placing samples on various supports such as metal, wood, and portland cement concrete during the counting period. The results indicated that there was a relationship between count rate and hydrogen content of the backing material. The count rate increased with increases in hydrogen content of the backing material.

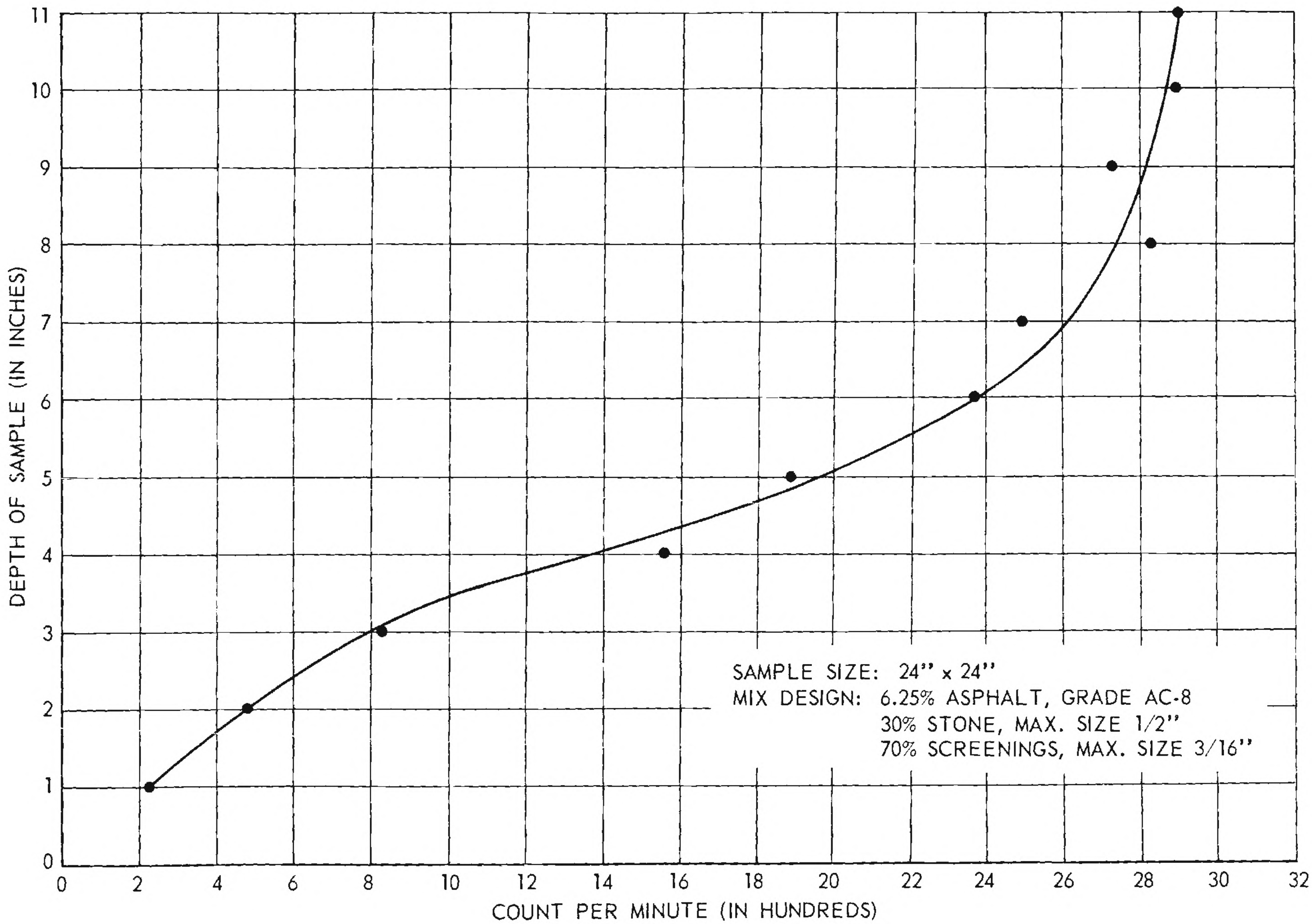


Figure 2. Determination of Infinite Sample Thickness Using Model P-21 Moisture Probe by Nuclear-Chicago.

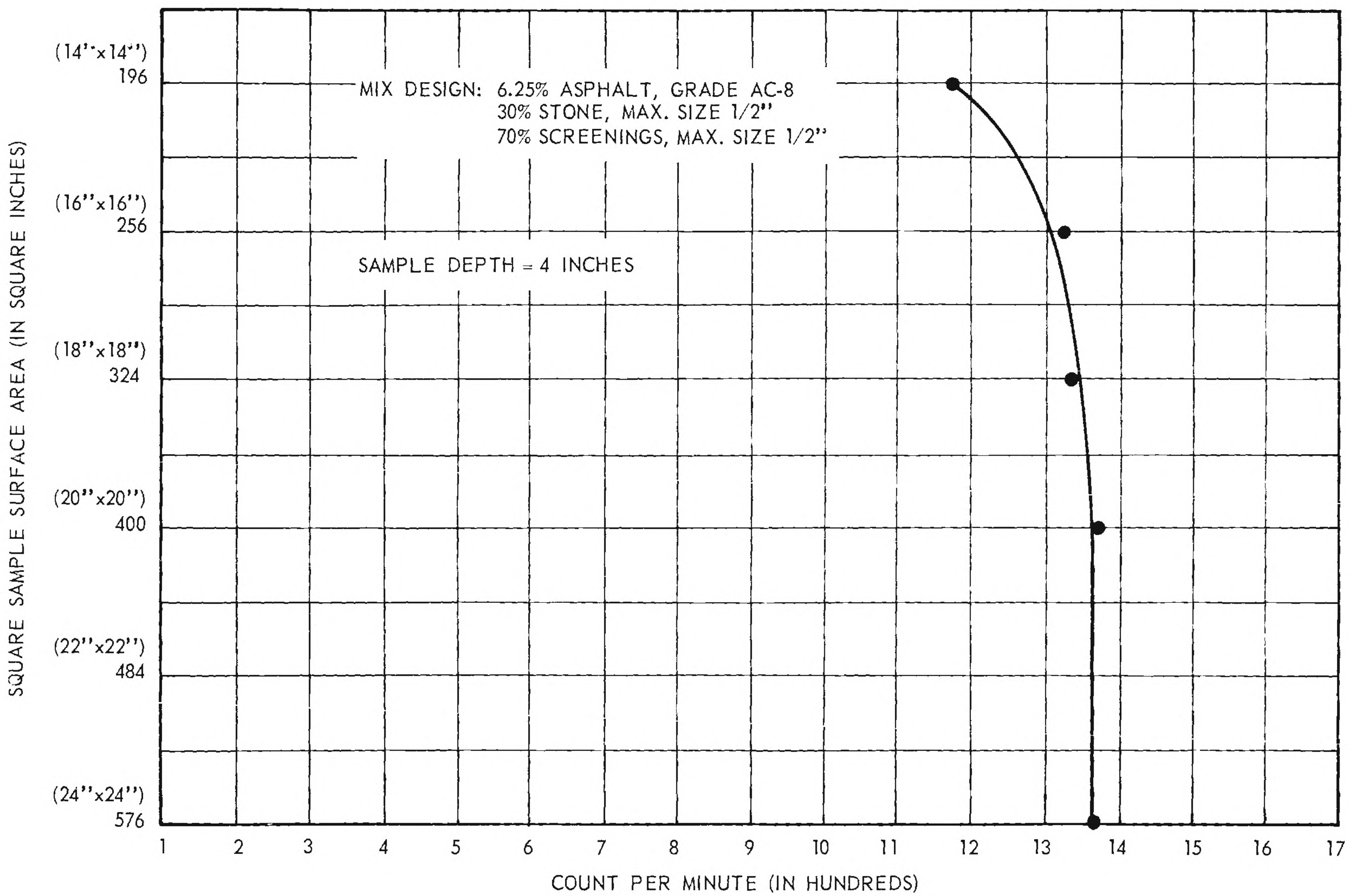


Figure 3. The Effect of Square Sample Surface Area on Count Rate Using Model P-21 Surface Moisture Probe by Nuclear-Chicago.

As normally placed, bituminous concrete has a relatively narrow range of density. A comparison was made between the count rates of loosely placed material and highly compacted material. The count rates indicated that with wide variations in density, there is variation in count rate. This test was conducted with bitumen content held at 6.25 per cent by weight of mix.

CHAPTER III

NEUTRON ACTIVATION

Method of Producing Neutrons

Neutrons were produced for activation of the Calcium-48 isotope in the mineral filler by the one-million-volt Van de Graaff positive ion accelerator on the Georgia Tech campus.

The Van de Graaff is a special type of electrostatic accelerator which has a highly insulated terminal and a means of maintaining the terminal at a very high static potential with respect to the ground. An ion injected into the high potential end of the machine is accelerated and directed by the electrostatic field downward through and evacuated acceleration tube to ground.

As an ion source, a mixture of ordinary and heavy hydrogen (deuterium) was used. The mixed beam of deuterons and H_2^+ ions at one million electron volts was directed through the evacuated tube onto a target of beryllium metal to produce the reaction

$${}_4Be^9 + {}_1d^2 \longrightarrow {}_5B^{10} + {}_0n^1 + \text{energy.}$$

A beam current of 48 microamperes was used to produce the neutrons shown in this reaction.

The thermal neutron moderator that was used in the portland cement experiments was also used in these experiments. The sample holder and method of positioning the sample in the neutron flux produced by the Van de Graaff was also similar to that used in the portland cement concrete experiments. The moderator was composed of cast paraffin surrounded by a cadmium shield to prevent the escape of the thermal neutrons produced in the moderator. The sample was positioned near the center of the moderator directly under the accelerating tube of the Van de Graaff. An indium foil was placed under the sample and activated with the sample. The purpose of the indium foil was to provide a base for the normalization of the sample activity produced in the Van de Graaff.

For additional information regarding the details of the experimental arrangement for the production of neutrons, see pages 6-8 in reference 3.

An increase in size of the bituminous concrete mortar specimens with respect to the portland cement concrete mortar specimens along with the decrease in the total calcium present in the specimens indicated a need for a higher neutron flux density. The higher flux density was achieved by raising the beam current from the 25 microamperes that was used in the portland cement concrete experiments to 48 microamperes.

Radiation Detection

No changes were made in the radiation detection and counting system that was used for portland cement with one minor exception. Because the bituminous concrete samples were 3/4 of an inch in height (see page 22, Chapter IV) while the portland cement concrete samples were only 1/4 of an inch in height, the mount for the scintillation crystals was modified to accommodate the larger sample.

Throughout the neutron activation phase of the program the detection and counting system was monitored to insure that there was no system drift either between samples or between days.

CHAPTER IV

TESTING PROGRAM

General Information

Cooperation of several bituminous concrete producers in the vicinity of Atlanta was secured for the sampling of their hot-mix batch plants. The criteria for plant selection was that the plant be scheduled to produce pavement of bituminous concrete containing mineral filler during late spring or early summer and that the plant have no unusual or unique characteristics. Because of an imposed time limitation the number of hot-mix batch plants sampled was reduced to one.

The plant chosen was a Cedar Rapids G-40 asphalt hot-mix batch plant owned by McIntosh Paving Company at Tyrone, Georgia. The batch capacity of the plant is 4000 pounds. A photograph and specifications of the plant are given in Figure B-1 in Appendix B.

The Georgia Tech Hobart Model C-100 laboratory mixer was also sampled. For this work a paddle mixing blade was used as is customary for mixes containing no aggregates larger than 3/4 of an inch. The batch capacity of the C-100 is 6000 grams. A picture of the C-100 and its specifications are shown in Figure B-2 in Appendix B.

Mix proportions for the field sampling and the laboratory sampling are given in Tables I and II, respectively, and the chemical analyses of these materials are shown in Table III.

Because of the design of the Cedar Rapids G-40, samples could not be drawn directly from the mixer. As an alternative, timed batches were

TABLE I

PROPORTIONS USED IN CEDAR RAPIDS G-40 HOT-MIX PLANT,
McINTOSH PAVING COMPANY

"E" Type Surface Mix as Specified by
State Highway Department of Georgia

Sieve Sizes: Passing	Sieve Sizes: Retained	Per Cent by Weight of Total Mix	Weight (Pounds)
3/4	1/2	13.3	533
1/2	1/4	38.3	1533
1/4	Pan	39.3	1571
Mineral Filler		2.6	103
Asphaltic Cement, AC-6		6.5	260
TOTAL		100.0	4000

TABLE II

PROPORTIONS USED IN HOBART C-100
LABORATORY MIXER, GEORGIA TECH

Typical "E" Type Surface Mix as Specified by
State Highway Department of Georgia

Sieve Sizes		Per Cent by Weight of Total Mix	Weight (Grams)
Passing	Retained		
3/4	1/2	5.58	279.0
1/2	3/8	11.22	561.0
3/8	4	22.44	1122.0
4	8	10.66	532.9
8	16	8.98	448.8
16	50	19.45	972.4
50	100	7.12	355.3
100	200	2.62	130.9
	Pan	2.62	130.9
Mineral Filler		2.81	140.3
Asphaltic Cement, AC-6		6.50	325.0
TOTAL		100.0	5000.0

TABLE III

CHEMICAL ANALYSIS OF MINERAL FILLER AND AGGREGATE

Chemical Compound	Per Cent by Weight
Mineral Filler	
Mineral Products Division, Georgia Marble Co., Tate, Georgia	
CaO	51.14
SiO_2	3.72
Al_2O_3	0.08
Fe_2O_3	0.20
SO_3	0.06
MgO	2.71
Ins. Res.	4.10
Loss on Ign.	42.24
K_2O	0.00
Na_2O	0.05
AsN_2O	0.05
Aggregate	
Tyrone Rock Products Co., Quarry No. 1, Tyrone, Georgia	
CaO	0.03
SiO_2	95.08
Al_2O_3	1.58
Fe_2O_3	1.50
SO_3	0.03
MgO	0.74
Ins. Res.	91.54
Loss on Ign.	0.68
K_2O	0.31
Na_2O	0.00
$AsNa_2O$	0.20

dumped into trucks where three samples were taken representative of three different points in the mixer.

The Hobart C-100 Mixer was sampled so that uniformity of mixing could be evaluated by comparing batches instead of a comparison of positions within a batch. This variation in sampling was necessitated by the small capacity of the C-100.

Design of the Experiment

The experiment was chosen to consist of five different mix times: 30, 45, 60, 90 and 180 seconds. Each mix time was repeated twice. An agreement with the commercial producer of bituminous concrete required that sampling be completed during one morning's operations and without interruption. It was, therefore, impossible to sample with true replication. As an alternative both mix times and samplings for each mix time were randomized so that the batches sampled were nested within mix times. A total of 60 samples were taken from the Cedar Rapids G-40 while only 20 samples were taken from the Hobart C-100.

Each sample taken was evaluated for Hveem stability, fineness modulus, and mineral filler content by neutron activation. Throughout the sampling and testing every effort was made to eliminate systematic errors.

Processing of Samples

Collecting of Samples

Samples collected in the field were returned to the laboratory for processing and testing. No effort was made to maintain sample temperature during transport. To insure uniform results, laboratory samples were also allowed to cool before further processing.

The samples were placed in a 300° F oven for 4 hours prior to processing. The field samples were then mixed for one minute to insure uniformity within each sample. Samples were then sectioned and quartered into the portions required for the various tests.

Hveem Stability Samples

Specimens for the Hveem stability test required 1200 grams of mix. They were constructed and treated according to the recommendations of the Asphalt Institute. (6) Stability specimens are shown in Figure 4.

Fineness Modulus

Fineness modulus determination required 1000 grams of mix from each sample. The asphaltic cement was first extracted in a centrifuge using a standard solvent. Gradation was determined by sieve analysis. Both extraction and sieve analysis were performed in accordance with the standards of the American Association of State Highway Officials. (7)

Mineral Filler

Specimens for the determination of mineral filler dispersion were required to be so small that larger aggregates had to be removed before the specimens were constructed. About 50 grams of hot mix were screened through a number 4 sieve. The passing material was then compacted into 3/4-inch-diameter by 3/4-inch-height polystyrene containers using a 5/8-inch steel mandrel. Figure 5 shows the prepared mortar specimens.

Six samples containing known amounts of material passing the number 200 sieve were prepared. Each sample was then passed through the number 4 sieve. The materials retained on the separation sieve and the

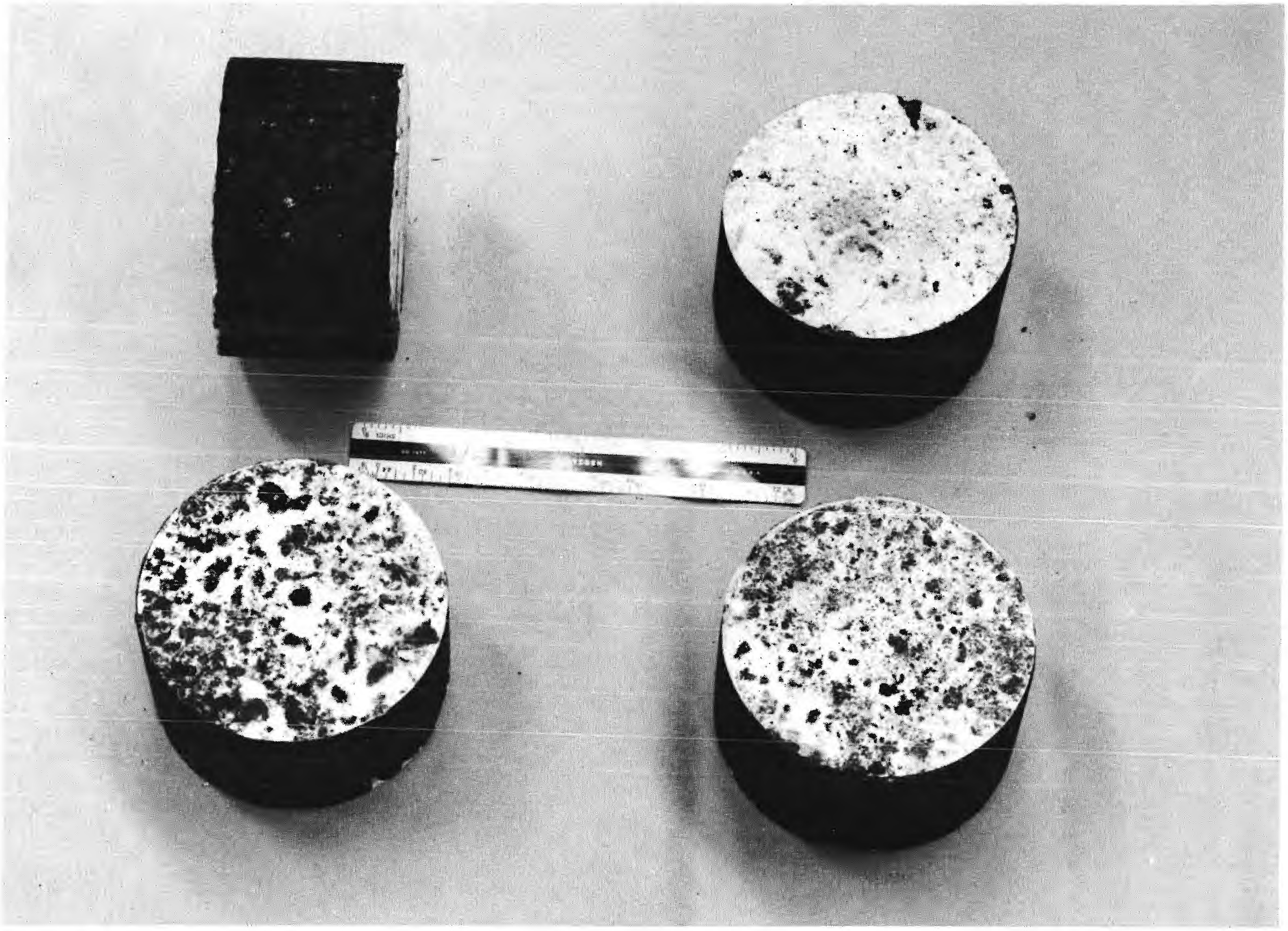


Figure 4. Bituminous Concrete Specimens Used to Evaluate Hveem Stability.

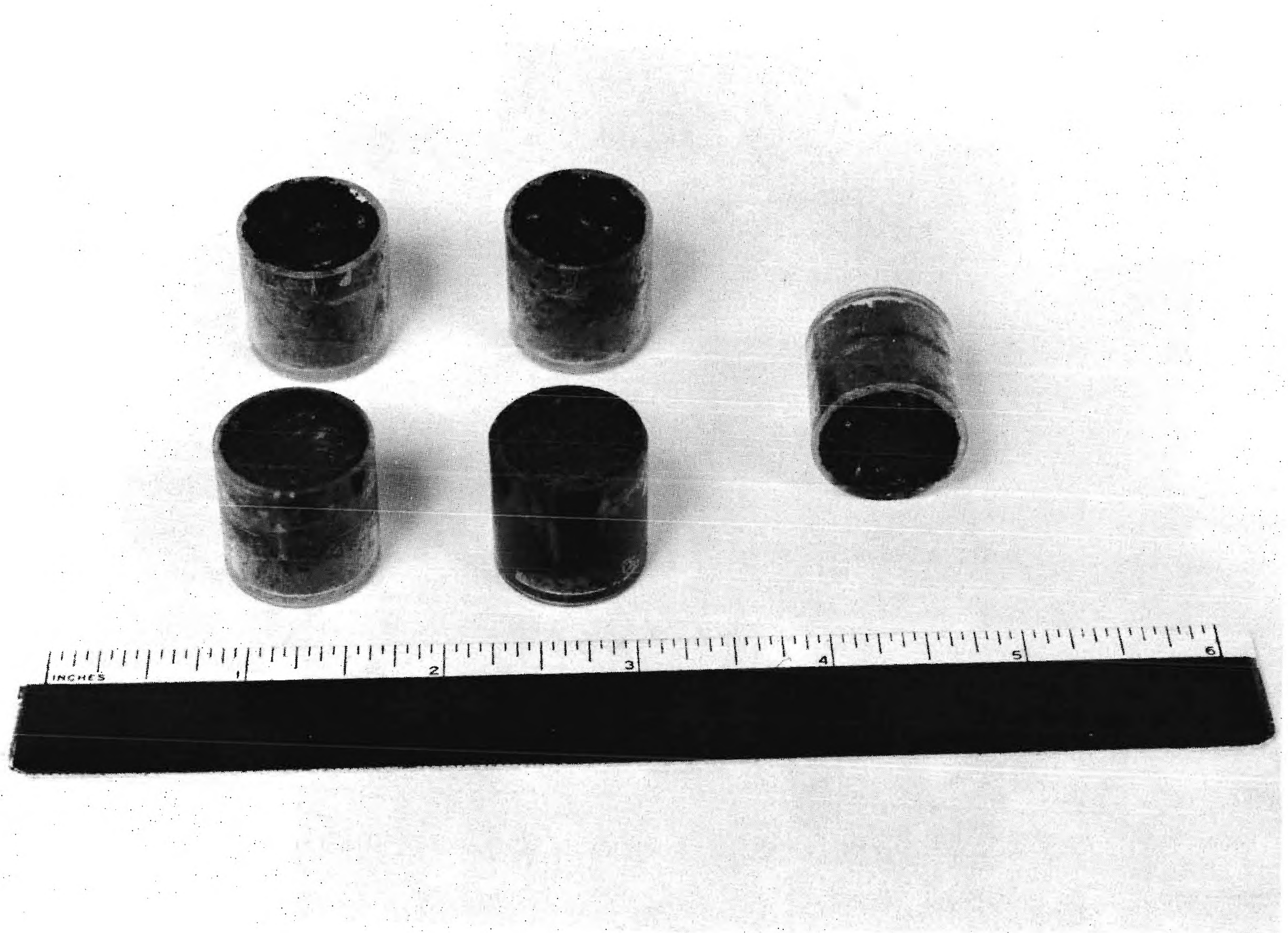


Figure 5. Bituminous Concrete Mortar Specimens Used to Evaluate Mineral Filler Content.

materials passing the separation sieve were then extracted and subjected to gradation analysis. The results of the gradation analyses allowed computation of the percentage of minus 200 material passing the separation sieve. With the assumption that mineral filler and minus 200 dispersed similarly in the mix, 45 per cent of the mineral filler passed the separation sieve.

Testing of Samples

The Hveem stability test was chosen as a test for strength because it theoretically eliminates the effect of cohesion of the bituminous cement. (8) The test required the use of a Hveem Stabilometer in conjunction with a standard controlled-rate loading machine as shown in Figure 6. Test conditions were as recommended by the Asphalt Institute. (6)

Determination of Mineral Filler Content

The mineral filler used throughout this research was a crushed limestone furnished by the Mineral Products Division, Georgia Marble Company, Tate, Georgia. All of the aggregate used came from the Tyrone Rock Products Company, Quarry No. 1, Tyrone, Georgia. Results of a chemical analysis of the mineral filler and the aggregate are presented in Table III.

Comparison between Table III of this report and Table VI of the report for that phase of the program dealing with portland cement concrete indicated that no new background investigations into the disintegrations of elements other than calcium were needed. As a check, the spectrum of an activated bituminous concrete mortar sample in Figure 7 compared favorably with the spectrum of an activated portland cement mortar sample.

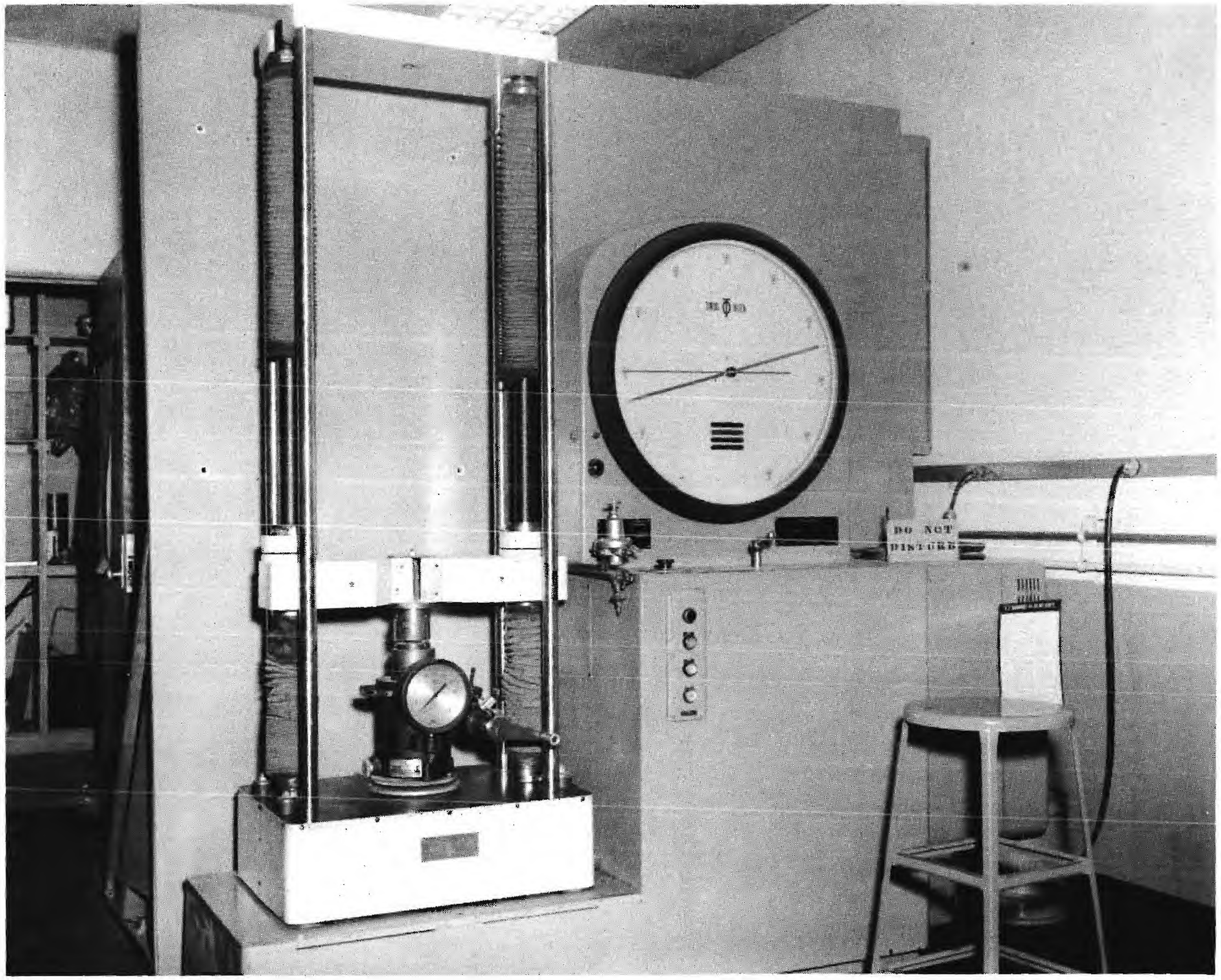


Figure 6. Hveem Stabilometer and Controlled-Rate Loading Machine.

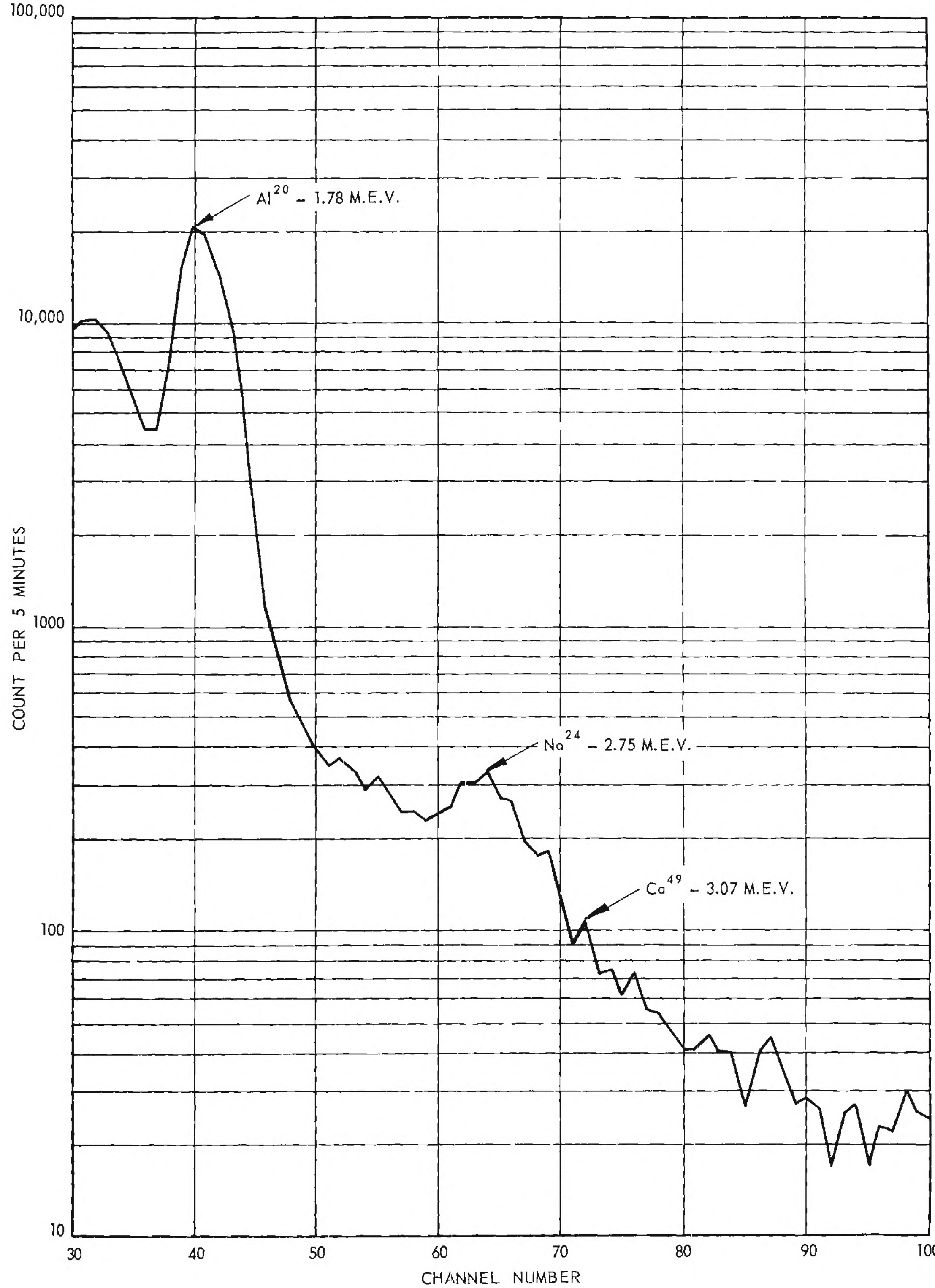


Figure 7. Gamma Ray Spectrum of Activated Bituminous Concrete Mortar Specimen.

As noted in Table III, the mineral filler contains 51.14 per cent calcium oxide. In addition, the normal range of mineral filler used in bituminous concrete is from 2 to 6 per cent. In view of these low figures, it was deemed desirable to increase the amount of calcium available for activation analysis by increasing the size of the asphaltic cement concrete activation sample in comparison to the portland cement concrete activation samples. The new sample size was calculated by first choosing an amount of calcium to be present in the sample. This choice was based on the work of the previous phase of the project dealing with portland cement concrete. The sample size was then calculated on the basis of the chosen amount of calcium. This calculation indicated that a 4/4-inch-diameter by 3/4-inch-height sample was required.

At the beginning of the neutron activation phase of the work the scintillation spectrometer (100 channel analyzer, crystals, and amplifier) was aligned and calibrated. The calibration placed the 3.07 mev pulse in channel 72. During each subsequent run using the spectrometer a plot of energy versus channel number was made as a check for system stability. A standard radioactive sample of cobalt-60 was used to locate the channels receiving the 1.17, 1.33 and 2.50 mev pulses. These points were then plotted as shown in the curve of Figure 8.

Figure 9 is the plot of a decay study made to determine the peak range of calcium-49. The range indicated was channels 66 through 76. The decay study also indicated that the Ca^{49} peak was positioned on the tail of a Na^{24} peak which accounted for the majority of the counts in the channels of interest. The Na^{24} peak was found to have a half-life of 15 hours or more. In order to divorce the counting statistics from the

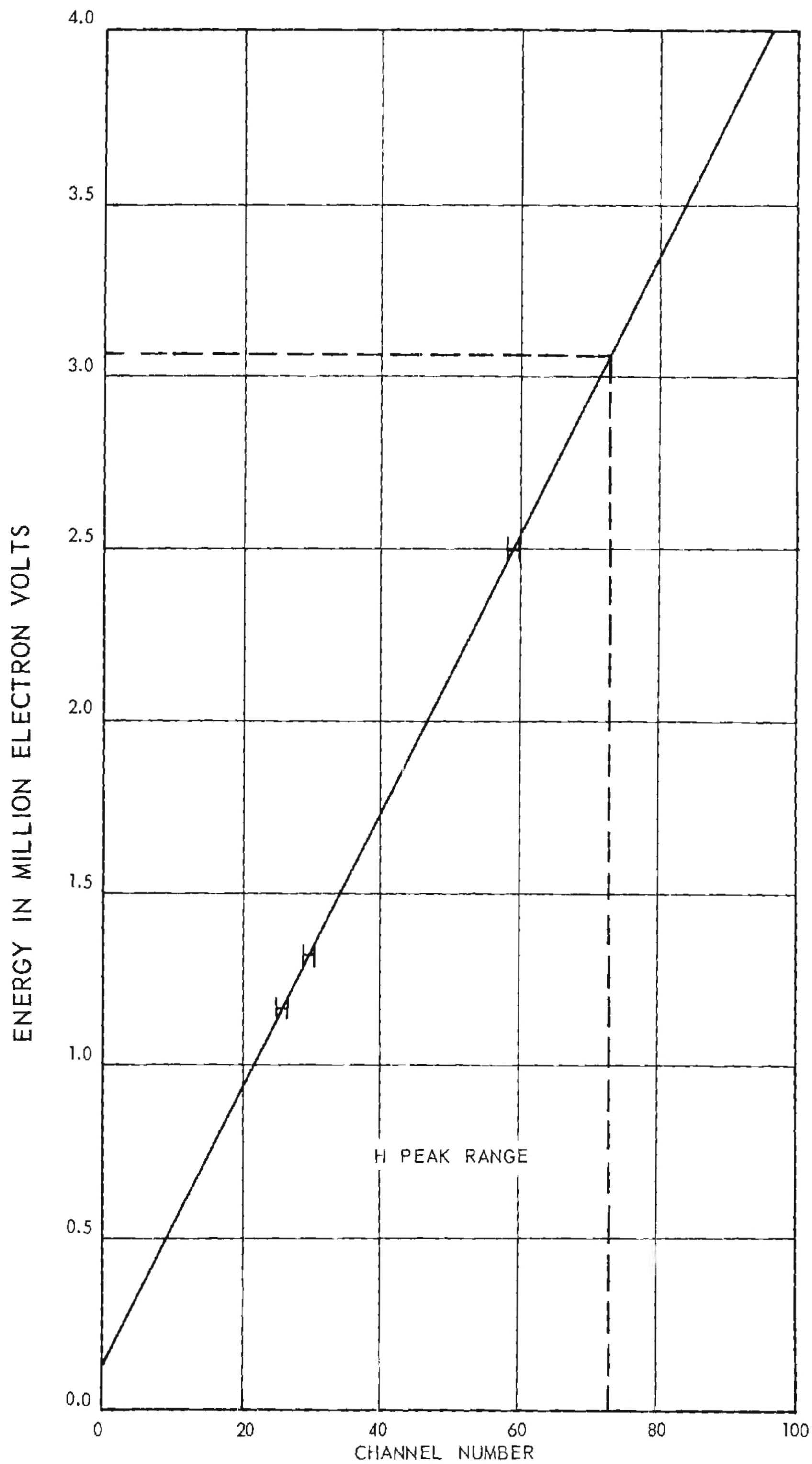


Figure 8. Calibration Curve for the Scintillation Spectrometer Using Co^{60}.

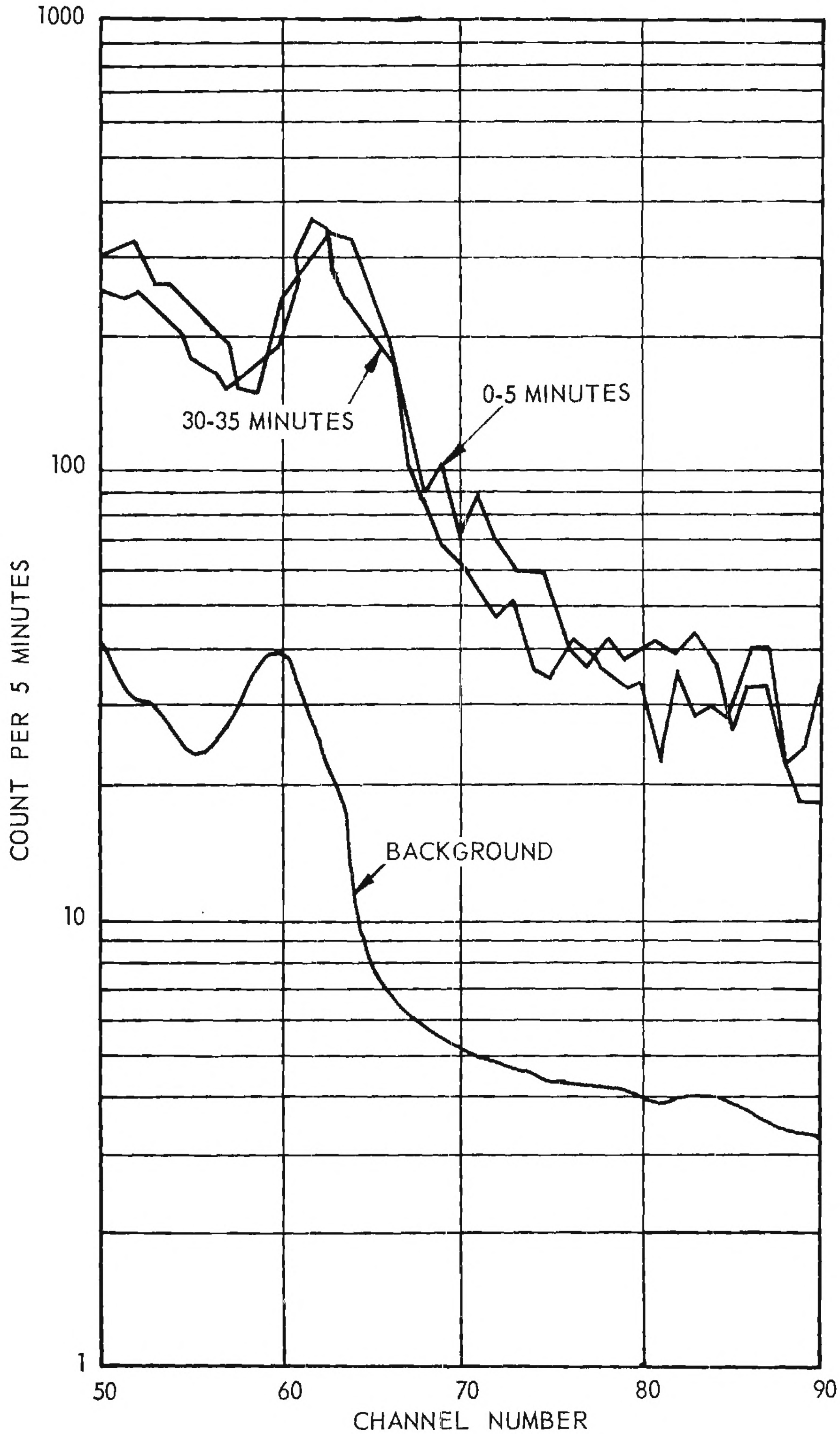


Figure 9. Decay of 3.07 MEV Peak in Channels 66 Through 76 of Calcium-49 in Bituminous Concrete Mortar Specimen.

influence of the Na^{24} peak, two counts were taken on each activation sample. The first 5 minute count was started 90 seconds after irradiation. The second count was started 30 minutes later. Since the half-life of the Na^{24} peak was much longer than the half-life of the Ca^{49} peak, the 30 minute interval had negligible effect on the count of the sodium peak while the activity of the calcium peak was reduced by more than 90 per cent. This logic was the basis for choosing a 30 minute interval. The sample count was taken as the differences between the total counts in channels 66 through 76 for the first and second counting periods.

A study of the decay of the total count in the 10 channels was made to insure that the counts recorded in the 10 channels were due to the Ca^{49} 3.07 mev decay. The half-life of this 3.07 mev gamma is 8.9 ± 0.2 minutes. (9) The decay of the 10 channels had a half-life of 8.6 minutes, as indicated in Table IV and Figure 10.

Each sample was irradiated for 10 minutes in the Van de Graaff. During this period the Van de Graaff beam varied in intensity. To eliminate the effects of the variation from the sample count, the neutron flux was monitored and the count adjusted to the value it would have been had the flux intensity been constant. The monitoring was accomplished using small pieces of Indium foil of known weight. The foil was irradiated along with the asphaltic cement concrete sample and both were counted at the same time. (3) The foil count was then normalized to a standard weight and count. The sample count could then be normalized to the adjusted foil count. An example of count normalization is given in Appendix C.

Bituminous concrete mortar samples containing known amounts of mineral filler were prepared for activation analysis. These samples were

TABLE IV

DECAY STUDY OF 3.07 MEV PEAK IN CHANNELS 66 THROUGH 76

Counting Time* (Minutes)	Count
0- 5	2263
9-14	1060
18-23	512
27-33	257

*Counting time started 90 seconds after the end of irradiation.

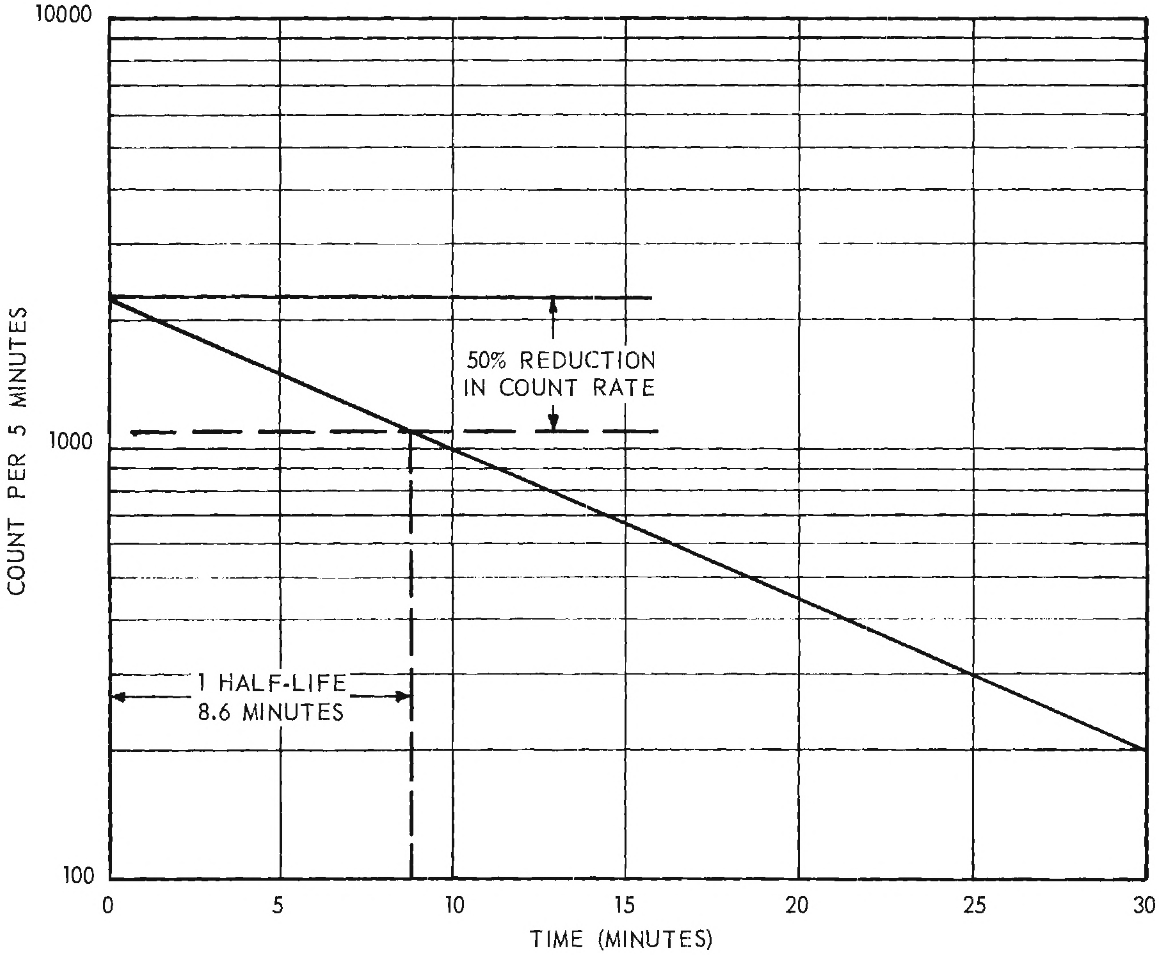


Figure 10. Half-Life Determination of 3.07 MEV Peak in Channels 66 Through 76.

used as standards to relate mineral filler content to the calcium-49 count. The relationship between the normalized standard counts and the mineral filler contents was established by means of a regression line computed by the method of least squares. This relationship is shown in Figure 11. A sample correlation coefficient and 95 per cent confidence limits were also computed and are shown. The sample correlation coefficient, r, was found to be 0.420. This number is used as an approximate measure of association between the observed data and the calculated line. The low coefficient was accepted as an indication that a linear relationship does exist between mineral filler content and count rate; however, the scatter of the data prevented an accurate determination of that relationship.

The scatter of the observed counts of the samples containing known amounts of mineral filler was responsible for both the low correlation coefficient and the wide confidence limits. This scatter was probably the result of several factors as follows:

1. Instability of neutron production. Neutron production using a beryllium target is very sensitive to extraneous material coating condensed or burned onto the target surface. As the Van de Graaff beam uncontrollably wandered across the target surface, clean or unbombarded portions of the surface had higher neutron production rates than contaminated portions. Furthermore, both the beam energy and the beam current were subjected to uncontrolled variation which affected the neutron production rate.

2. Low mineral filler content. The standard samples used to develop the curve of Figure 11 contained from zero to 1.1 grams of mineral filler. At the low end of this range the counting statistics were very

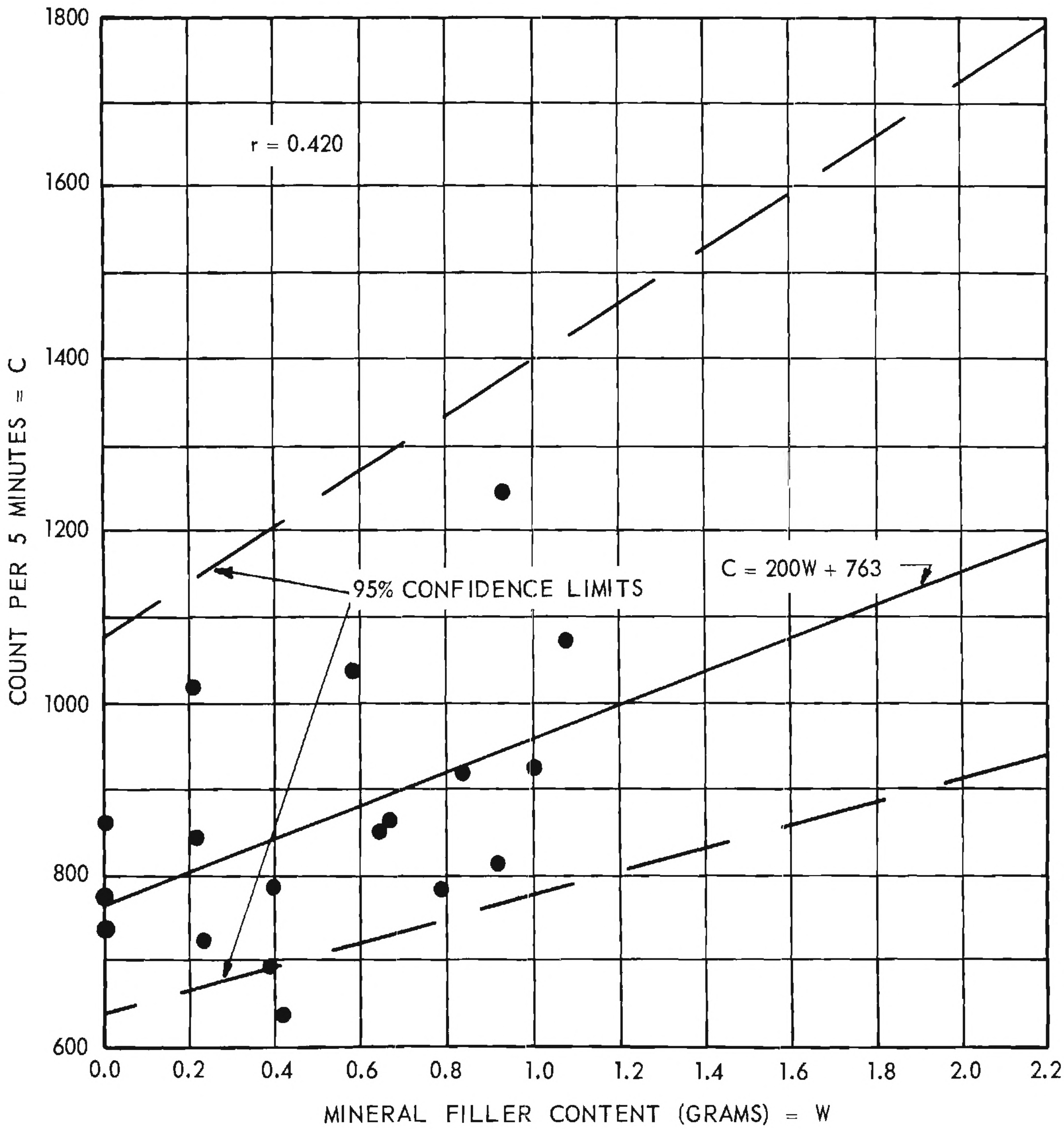


Figure 11. Mineral Filler Content Versus Count Chart.

poor. For example, when the calcium-49 count was 800, the estimate of the standard deviation was the square-root of 800 or 28.

3. Nonuniform standards. Regardless of the care with which the standard samples were constructed, there exists the possibility that the constituents of the samples were segregated. The effects of such segregation would be a scattering of results, as was obtained.

4. Low thermal neutron flux. Approximate calculations indicated that the thermal neutron flux at the sample irradiation point was about 5×10^6 thermal neutrons per square centimeter per second. This low flux coupled with the low calcium content would produce errant counts.

The normalized counts of the field and laboratory samples were then used to enter the chart of Figure 11 to determine values for the mineral filler content.

CHAPTER V

RESULTS

Analysis of Variance

Analysis of Variance was used to analyze the data collected. This procedure would allow comparison of certain quantitative physical characteristics as influenced by controllable variables. The quantitative physical characteristics are referred to as dependent variables and the controllable variables are independent.

The dependent variables were mineral filler content, stability, and fineness modulus. Both mineral filler content and fineness modulus (gradation) appeared to be independent variables because mineral filler and aggregates were placed in the mix in controlled amounts. This apparent independence was not real because the mineral filler and aggregates entered the mixing apparatus in segregated batches. The point values of mineral filler content and fineness modulus were, therefore, dependent on the uniformity of mixing.

The selected independent variables were mixing time, position in the mixer, and batch. Batch was analogous to replication and differed only in that batches were nested within mixing time because of restrictions on field sampling.

Computations for the sum of squares, degrees of freedom, and expected mean squares were performed on a computer. (10) The mathematical models for the variance were similar to the model used in the previous report dealing with portland cement concrete.

Mineral Filler Content

Utilizing the form of computation exemplified in Appendix C and the chart in Figure 11, the determination of the mineral filler content of the samples subjected to activation analysis was possible. Tables D-I and D-II give the results of this process. These results contain a preponderance of zero values of mineral filler content. For this reason, it was felt that analysis of variance of the mineral filler content data would produce no useable information. The high incidence of zeros in the values might be attributed to any one or a combination of several effects as follows:

1. Of the points used to derive the curve of Figure 11, very few were in the mineral filler content range of the unknown samples. This produced a curve of low sensitivity at the low mineral filler content end.

2. Aside from the 55 per cent loss of mineral filler from the unknowns during the separation process, there was some unexplained difference between the standard activation samples and the unknown activation samples.

3. The 55 per cent loss of mineral filler from the unknowns left the unknown activation samples with insufficient mineral filler to produce a statistically reliable calcium-49 count.

However, the normalized calcium-49 counts in Tables D-III and D-IV were subjected to analysis of variance as shown in Tables D-V and D-VI. The analyses indicate that mix time, batch, position and interactions of these variables have no significant effect on the calcium-49 count at the 5 and 1 per cent levels of significance.

Inspection of Table D-III indicates that the calcium-49 count of the field sampling produced a range from 468 to 990 normalized counts per 5 minutes. The range of counts for the laboratory sampling was from 354 to 853 normalized counts per 5 minutes as shown in Table D-IV. These wide ranges coupled with the analyses of variance discussed in the previous paragraph indicate that the variations in data due to effects of the independent variables and their interactions are very small compared to the variations due to effects of uncontrolled variables.

Aggregate Fineness Modulus

Tables D-XII and D-XIII give the values of aggregate fineness modulus of the samples collected during the experiment. Results of the analysis of variance are shown in Tables D-IX and D-X.

From Tables D-IX and D-X it may be noted that none of the independent variables or their interactions have significant effect on the aggregate fineness modulus at the 5 and 1 per cent levels.

Hveem Stability

Hveem stability is used by many state highway departments as an index of bituminous concrete quality. It is, however, rarely used alone because the Hveem stability value determined for one particular test specimen depends to a certain extent on the arrangement of the largest aggregate particles within the specimen.

Tables D-XI and D-XII show the stabilities obtained by the Hveem method from the samples collected. Tables D-XIII and D-XIV show the computed analyses of variance for Hveem stability.

Table D-XII indicates that the interaction of mixing time and position was significant at the 5 per cent level.

In Tables D-XIII and D-XIV the hypothesis that the different batches do not affect Hveem stability is rejected. The effect of different batches was significant at the 10 per cent level in the analyses of variance for calcium-49 count and fineness modulus as shown in Tables D-V and D-IX, respectively. While the 10 per cent level of significance was not considered sufficiently rigorous for the purpose of comparison it is given here to indicate continuity of the batch effect throughout the results. These results show the basic nonrepeatibility of uniformity of mixing from batch to batch, regardless of mixing time or position in the mixer. Mixing time and position are not significant.

CHAPTER VI

SUMMARY OF RESULTS AND CONCLUSIONS

Summary of Results

Results obtained for mineral filler content, fineness modulus, Hveem stability, and asphaltic cement content are as follows:

1. Mineral Filler Content: The relationship between mineral filler and calcium-49 count was not determined to the degree of accuracy necessary for predicting unknown mineral filler contents. The analysis of variance for the calcium-49 count indicated that all main and interaction effects for both mixers studied were not significant.

2. Aggregate Fineness Modulus: Mixing time, batch, position and interactions of these variables had no significant effect on the fineness modulus for both mixers studied.

3. Hveem Stability: For both mixers studied, differences from batch to batch were very significant for Hveem stability. All other main and interaction terms were not significant with the exception of significance at the 5 per cent level for the interaction of mix time and position. No reasons can be assigned to this difference.

4. Asphaltic Cement Content: Using neutron backscatter techniques, sample depth, surface area of a square sample, sample backing material, and sample density affect the count rate due to asphaltic cement.

Conclusions

1. Activation analysis using the Van de Graaff Accelerator with a beryllium or tritium target does not appear to be a feasible method for

determining the mineral filler content for bituminous concrete mortar samples. However, the authors feel that a more stable and higher neutron flux, as will be produced by the reactor now under construction at Georgia Tech or as can be produced by neutron generators, will render the method feasible.

A routine testing method for mineral filler content of bituminous concrete would require, among other things, portable testing equipment. For this reason activation analysis is not a feasible method for routine testing. Radioactive neutron sources, such as the radium-beryllium mixture, appear to be a logical choice for neutron production. However, if the source is large enough to produce sufficient neutrons, the shielding requirements of the source render it nonportable and the cost of the source is prohibitive. The authors conclude that activation analysis is not a feasible method for routine determination of mineral filler content of bituminous concrete mortar samples.

2. It may be concluded from the data collected that mixing times of 30 seconds or greater have no effect on the uniformity of mixing as measured by Hveem stability, fineness modulus or calcium count. However, differences from batch to batch are very significant for Hveem stability and less significant for fineness modulus and calcium count. Position and interactions have no effect on the uniformity of mixing with the exception of the interaction of mixing time and position for Hveem stability which is significant at the 5 per cent level. No reason can be assigned to this difference, and it is assumed to be chance error.

3. Neutron backscatter techniques do not meet the requirements of a testing method for determining asphaltic cement content of in-place

bituminous concrete pavements. Rejection of the method is based on the fact that with usual depths of pavement lifts of 1 to 3 inches, as shown in Figure 1, the lift backing material would be the major determinant of backscatter count rate.

Using controlled testing environment, the backscatter method could be used with a large test specimen. However, uniform density is difficult to achieve in large samples under field conditions.

Using controlled testing environment and small test specimens, the backscatter method would incur problems of devising an efficient testing geometry which would produce the required sensitivity of results.

CHAPTER VII

RECOMMENDATIONS

Uniformity of Mixing

Research in the uniformity of mixing of bituminous concrete at various mixing times should be continued using mineral filler dispersion as a measure of uniformity of mixing. However, a higher and more stable neutron flux is required for further research. The authors do not believe that research using the reactor under construction at Georgia Tech would produce an economical routine testing method. However, such research would produce information of great benefit to state highway departments, producers of bituminous concrete, and mixing equipment manufacturers.

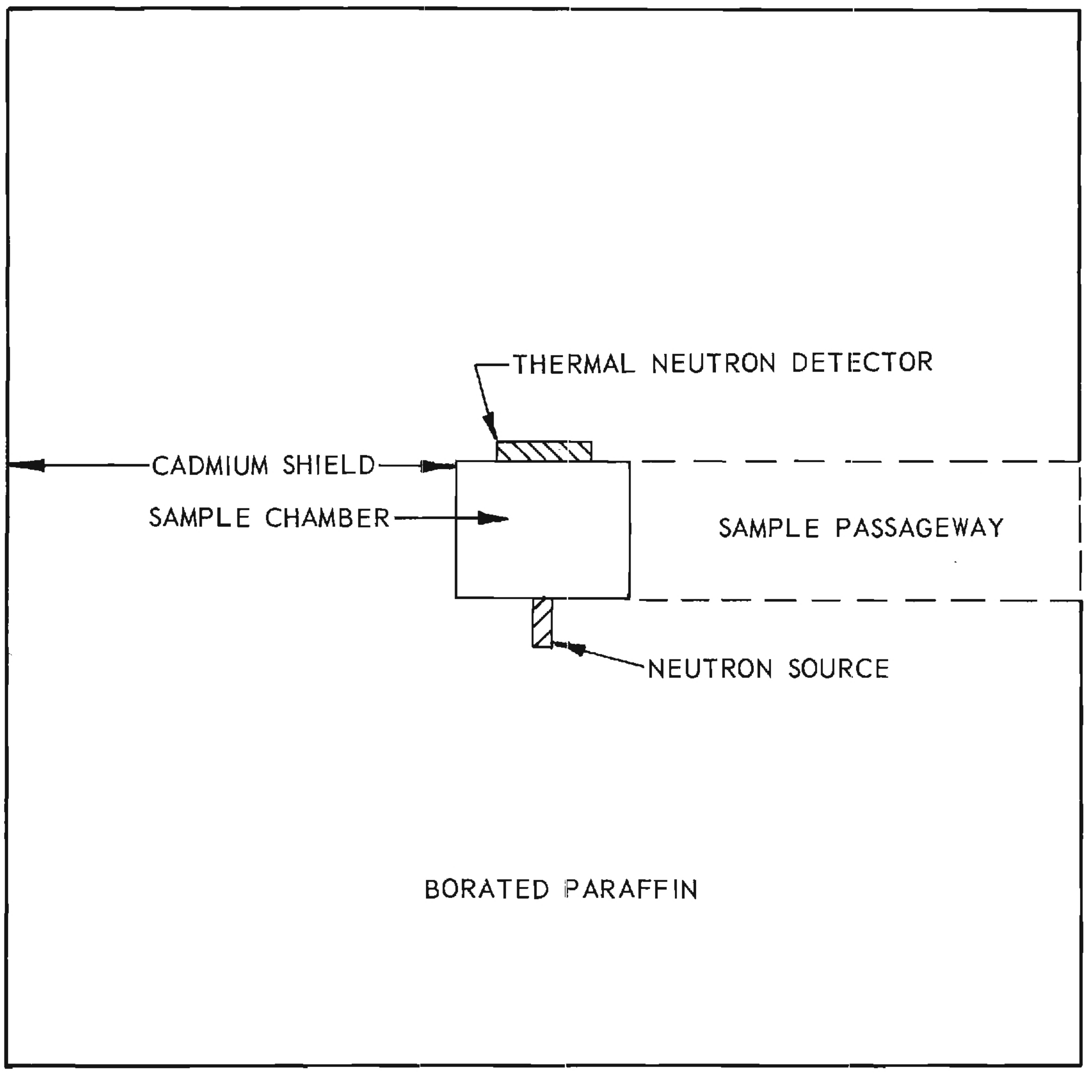
Radioactive isotope neutron sources are usually not available which meet flux and cost requirements of a routine testing method. Two possible isotope sources might be the American-beryllium mixture and the polutonium-beryllium mixture for neutron production to meet this purpose.

Asphaltic Cement Content

A method for determining asphaltic cement content in the laboratory was developed at the University of Wyoming. (11) This method uses the neutron attenuation principle wherein the test specimen is placed between the neutron source and the neutron detector. The researchers noted that their method probably will not replace current methods because of the variability of results, cost of equipment, and unwieldness of the equipment.

The Wyoming research in conjunction with this research indicates that a gauge to measure asphaltic cement content at the plant site is feasible. Such a gauge would require controlled sample size and density, a detection system capable of differentiating between high energy and thermal neutrons, a stable source of thermal neutrons, and a controlled environment for the sample during the test. Development of this gauge should start immediately.

The authors present the sketch in Figure 12 as a possible development of a gauge to measure asphaltic cement content. A program to develop this gauge should include studies of neutron sources, testing geometry, and optimum specimen size.



POSSIBLE NEUTRON SOURCES
1. AMERICAN – BERYLLIUM
2. PLUTONIUM – BERYLLIUM

Figure 12. Possible Development of a Gauge to Measure Asphaltic Cement Content of Bituminous Concrete.

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APPENDIX A

BITUMINOUS CONCRETE MIXER SPECIFICATIONS

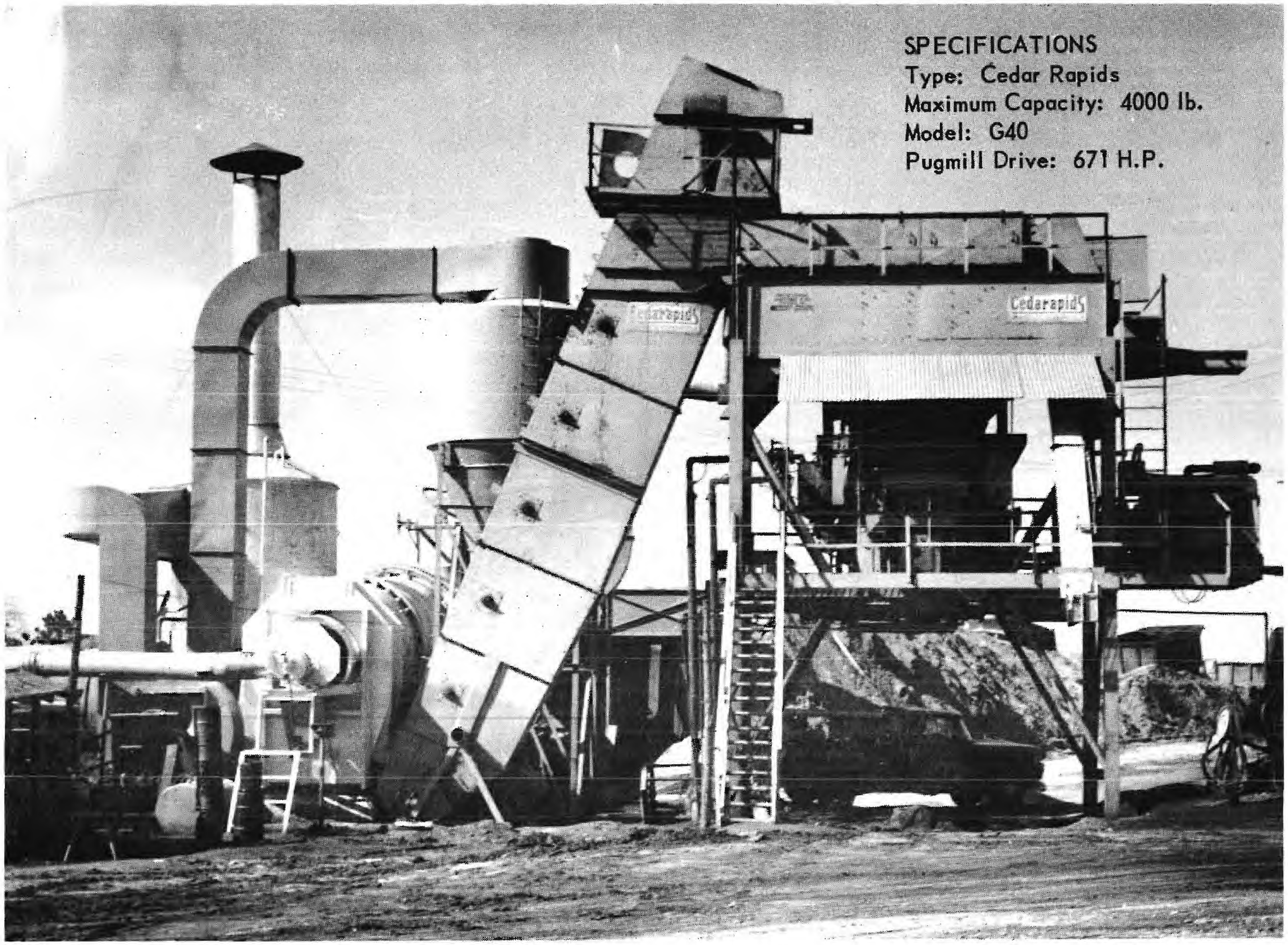

Figure A-1. Specifications of Mixer for McIntosh Paving Company, Tyrone, Georgia.

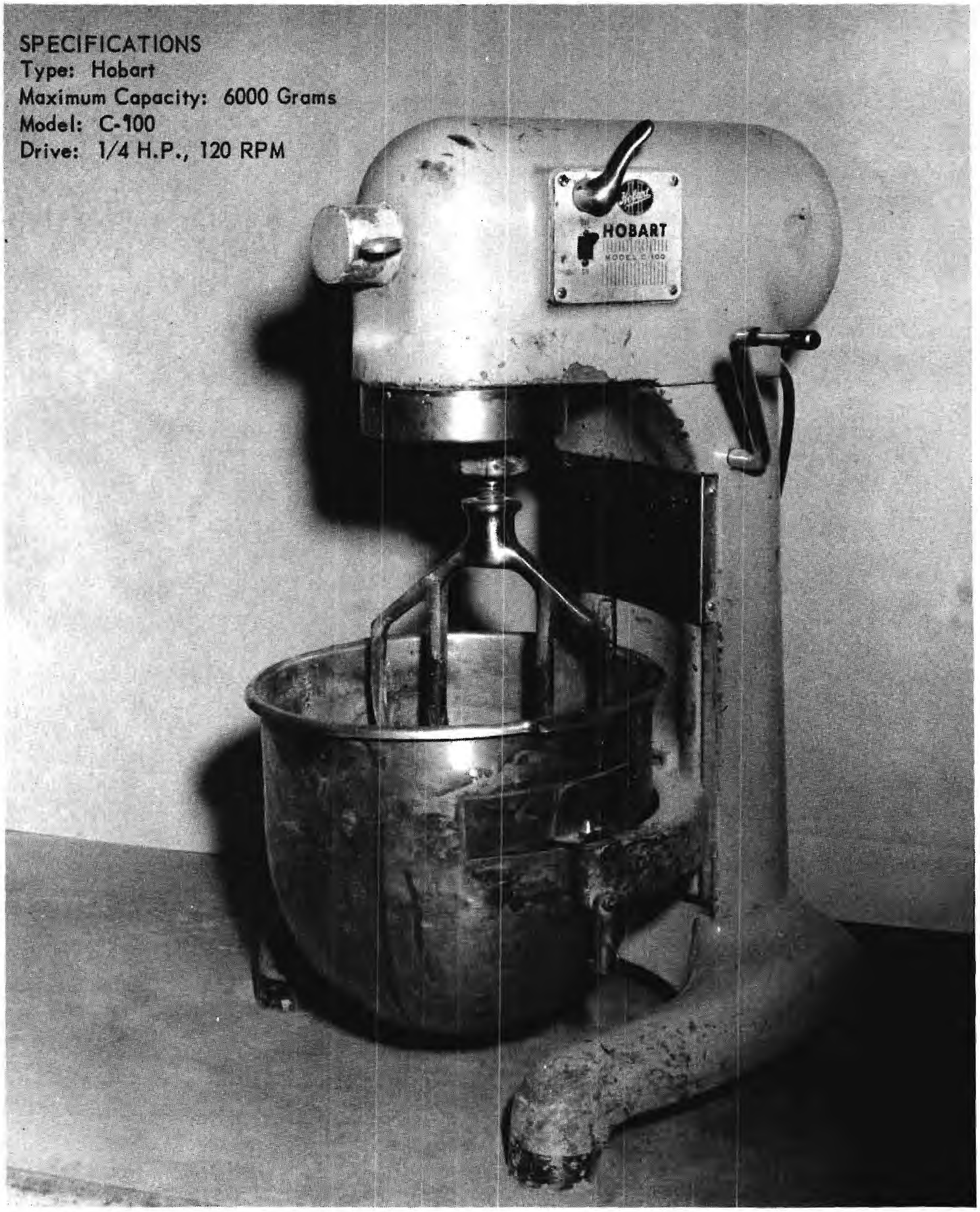

Figure A-2. Specifications of Laboratory Mixer for Georgia Tech.

APPENDIX B

EXAMPLE CALCULATION FOR NORMALIZING CALCIUM-49 COUNT PER 5 MINUTES OF BITUMINOUS CONCRETE MORTAR SPECIMENS AND DETERMINING MINERAL FILLER CONTENTS

TABLE B-I

EXAMPLE CALCULATION FOR NORMALIZING CALCIUM-49 COUNT PER 5 MINUTES OF BITUMINOUS CONCRETE MORTAR SPECIMENS AND DETERMINING MINERAL FILLER CONTENTS

	Indium Foil Data			Sample Count			
Sample Number	Foil Count(N_t) Per 5 Minutes	Foil Weight (Mg)	N_t Per 100 Mg	First Count Channels 66-76	Second Count Channels 66-76	Sample Count (Difference)	Sample Count for N_t=15000
325	10,776	81.5	8,782	2446	1573	873	990

	Mineral Filler Content				
Sample Number	Sample Weight (Grams)	Container Weight (Grams)	Net Sample Weight (Grams)	Weight Mineral Filler* (Grams)	Mineral Filler Content (Grams Filler Per Gram Mix)
325	12.125	1.870	10.255	1.160	0.113

*See Figure 11.

APPENDIX C

TABLES OF RESULTS AND ANALYSIS OF VARIANCE

TABLE C-I

MINERAL FILLER CONTENT OF BITUMINOUS CONCRETE MORTAR SPECIMENS IN GRAMS MINERAL FILLER PER GRAM MIX FROM TYRONE PLANT

Batch	Position in Discharge	Sample	Mixing Time (Seconds) 30	45	60	90	180
1	1	1	0	0	0.072	0.055	0
		2	0	0	0	0	0
	2	1	0.102	0	0	0.113	0.019
		2	0	0	0	0.059	0.016
	3	1	0.040	0	0	0	0
		2	0	0	0	0	0.060
2	1	1	0.077	0	0.059	0.057	0.016
		2	0	0	0	0	0
	2	1	0	0	0.101	0	0
		2	0	0	0.045	0.009	0
	3	1	0.082	0	0	0	0.071
		2	0.070	0	0.033	0	0

TABLE C-II

MINERAL FILLER CONTENT OF BITUMINOUS CONCRETE MORTAR SPECIMENS IN GRAMS MINERAL FILLER PER GRAM MIX FROM GEORGIA TECH LABORATORY MIXER

Batch	Sample	Mixing Time (Seconds) 30	45	60	90	180
1	1	0	0	0	0	0
	2	0	0	0	0	0
2	1	0	0	0	0	0.047
	2	0	0	0	0	0.011

TABLE C-III

NORMALIZED CALCIUM-49 COUNT PER 5 MINUTES OF BITUMINOUS CONCRETE MORTAR SPECIMENS FROM TYRONE PLANT

Batch	Position in Discharge	Sample	Mixing Time (Seconds) 30	45	60	90	180
1	1	1	662	531	879	870	753
		2	676	471	738	744	738
	2	1	963	562	573	990	800
		2	705	548	649	876	796
	3	1	847	727	636	651	687
		2	760	632	709	755	882
2	1	1	927	643	891	883	799
		2	728	549	762	562	493
	2	1	664	697	974	713	716
		2	648	685	853	786	479
	3	1	929	606	706	655	906
		2	902	670	823	720	468

TABLE C-IV

NORMALIZED CALCIUM-49 COUNT PER 5 MINUTES OF BITUMINOUS CONCRETE MORTAR SPECIMENS FROM GEORGIA TECH LABORATORY MIXER

Batch	Sample	Mixing Time (Seconds) 30	45	60	90	180
1	1	572	712	497	722	735
	2	589	531	559	724	709
2	1	582	742	585	634	853
	2	354	706	672	604	784

TABLE C-V

ANALYSIS OF VARIANCE FOR NORMALIZED CALCIUM-49 COUNT PER 5 MINUTES OF BITUMINOUS CONCRETE MORTAR SPECIMENS FROM TYRONE PLANT

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Tests F	F Tests $F_{0.05}$	F Tests $F_{0.01}$
Mixing Time	241,515.00	4	60,378.75	1.988	5.19	11.4
Batches (within time)	151,893.66	5	30,378.73	2.477*	2.53	3.70
Position	4,367.10	2	2,183.55	0.141	4.46	8.65
Time x Position	123,600.38	8	15,450.05	1.080	3.07	5.06
Batch x Position (within time)	143,029.76	10	14,302.98	1.166	2.16	2.98
Residual	367,881.92	30	12,262.73			
TOTAL	1,032,287.8	59				

*Significant at the 10 per cent level.

TABLE C-VI

ANALYSIS OF VARIANCE FOR NORMALIZED CALCIUM-49 COUNT PER 5 MINUTES OF BITUMINOUS CONCRETE MORTAR SPECIMENS FROM GEORGIA TECH LABORATORY MIXER

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Tests		
				F	$F_{0.05}$	$F_{0.01}$
Mixing Time	144,680.3	4	36,170.08	3.38	5.19	11.4
Batches (within time)	53,493.75	5	10,698.75	2.05	3.33	5.64
Residual	52,078.5	10	5,207.85			
TOTAL	250,252.55	19				

TABLE C-VII

AGGREGATE FINENESS MODULUS, TYRONE PLANT

Batch	Position in Discharge	Mixing Time (Seconds) 30	45	60	90	180
1	1	3.33	3.32	3.59	3.45	3.19
	2	3.21	3.22	3.51	3.33	3.40
	3	3.43	3.21	3.38	3.47	2.98
2	1	3.50	3.39	3.26	3.65	3.29
	2	3.46	3.26	3.41	3.66	3.23
	3	3.52	3.26	3.40	3.68	3.34

TABLE C-VIII

AGGREGATE FINENESS MODULUS, GEORGIA TECH LABORATORY MIXER

Batch	Mixing Time (Seconds) 30	45	60	90	180
1	3.65	3.38	3.33	3.77	3.39
2	3.39	3.44	3.52	3.32	3.26

TABLE C-IX

ANALYSIS OF VARIANCE FOR FINENESS MODULUS, TYRONE PLANT

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Tests: F	$F_{0.05}$	$F_{0.01}$
Mixing Time	0.385	4	0.096	3.00	5.19	11.4
Batches (within time)	0.160	5	0.032	2.64*	3.33	5.64
Position	0.00965	2	0.00482	.562	4.1	7.56
Time x Position	0.0687	8	0.00858	.709	3.07	5.06
Batch x Position (within time)	0.121	10	0.0121			
TOTAL	0.744	29				

*Significant at the 10 per cent level.

TABLE C-X

ANALYSIS OF VARIANCE FOR FINENESS MODULUS, GEORGIA TECH LABORATORY MIXER

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Tests: F	F Tests: $F_{0.05}$	F Tests: $F_{0.01}$
Mixing Time	.063	4	.0158	.485	5.19	11.4
Batches (within time)	.163	5	.0326			
TOTAL	.226	9				

TABLE C-XI

HVEEM STABILITY, TYRONE PLANT

Batch	Position in Discharge	Sample	Mixing Time (Seconds) 30	45	60	90	180
1	1	1	28	48	28	53	55
		2	28	37	44	57	48
	2	1	42	38	42	48	45
		2	30	48	39	50	45
	3	1	33	44	52	48	51
		2	37	31	52	48	43
2	1	1	36	26	35	35	49
		2	28	27	49	44	44
	2	1	47	33	37	39	54
		2	43	31	34	36	57
	3	1	46	36	48	34	42
		2	36	31	45	30	44

TABLE C-XII

HVEEM STABILITY, GEORGIA TECH LABORATORY MIXER

Batch	Sample	Mixing Time (Seconds) 30	45	60	90	180
1	1	39	55	64	54	41
	2	40	57	63	48	42
2	1	52	46	23	44	54
	2	37	59	39	52	62

TABLE C-XIII

ANALYSIS OF VARIANCE FOR HVEEM STABILITY, TYRONE PLANT

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Tests: F	$F_{0.05}$	$F_{0.01}$
Mixing Time	1,182.43	4	295.61	1.26	5.19	11.4
Batches (within time)	1,169.50	5	233.9	9.64*	2.53	3.70
Position	43.23	2	21.62	0.21	4.46	8.65
Time x Position	840.27	8	105.03	3.11**	3.07	5.06
Batch x Position (within time)	337.50	10	33.75	1.39	2.16	2.98
Residual	728.00	30	24.27			
TOTAL	4,300.93	59				

*Significant at the 1 and 5 per cent levels.

**Significant at the 5 per cent levels.

TABLE C-XIV

ANALYSIS OF VARIANCE FOR HVEEM STABILITY, GEORGIA TECH LABORATORY MIXER

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Tests: F	F Tests: $F_{0.05}$	F Tests: $F_{0.01}$
Mixing Time	317.7	4	79.43	0.29	5.19	11.4
Batches (within time)	1,374.75	5	274.95	6.70*	3.33	5.64
Residual	410.5	10	41.05			
TOTAL	2,102.95	19				

*Significant at the 1 and 5 per cent levels.